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Benefits Analysis of Alternative Secondary National Ambient Air Quality Standards for Sulfur Dioxide and Total Suspended Particulates. Volume 2

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16. ABSTRACT

This study was initiated by EPA's Office of Air Quality Planning and Standards as part of its review of the current secondary standards for sulfur dioxide (SO_2) and total suspended particulates (TSP). The study has drawn heavily upon new data and research advances from the past decade or so, and considerably expands the information available about the economic benefits of selected air pollution control regulations.

The theoretical base for the analysis is a series of models structured to simulate optimizing behavior by members of society in markets where air quality has an influence. Groups of these members of society are referred to as "economic sectors." The four sectors analyzed in this study are: 1) Household, 2) Agricultural, 3) Manufacturing, and 4) Electric Utilities.

Consideration of optimizing behavior allows for the possibility of differing responses to air pollution. This reduces the potential for biased estimates and also allows inferences consistent with the willingness-to-pay criterion.

Benefits were calculated for the current and an alternative (24-hour averaging time) SO_2 secondary standard and for the current TSP secondary standard. Subsequent to a public peer review meeting, additional analyses were undertaken to assess the validity of the benefit estimates.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Economic Sectors Benefits Analyses Optimizing Behavior Secondary National Ambient Air Quality Standards Air Pollution, SO_2 and TSP	→ This document is on the benefits analysis of households	

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Volume II

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FINAL ANALYSIS

BENEFITS ANALYSIS OF ALTERNATIVE SECONDARY NATIONAL AMBIENT AIR QUALITY STANDARDS FOR SULFUR DIOXIDE AND TOTAL SUSPENDED PARTICULATES

VOLUME II

Benefits Analysis Program
Economic Analysis Branch
Strategies and Air Standards Division
Office of Air Quality Planning and Standards

U.S. Environmental Protection Agency

Research Triangle Park
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August 1982

PREFACE

This report was prepared for the U.S. Environmental Protection Agency by MATHTECH, Inc. The report is organized into six volumes containing a total of 14 sections as follows:

Volume I

- Section 1: Executive Summary
- Section 2: Theory, Methods and Organization
- Section 3: Air Quality and Meteorological Data

Volume II

- Section 4: Household Sector
- Section 5: Residential Property Market
- Section 6: Labor Services Market

Volume III

- Section 7: Manufacturing Sector
- Section 8: Electric Utility Sector

Volume IV

- Section 9: Agricultural Sector

Volume V

- Section 10: Extrapolations
- Section 11: Bibliography

Volume VI

- Section 12: Summary of the Public Meeting
- Section 13: Analysis of Pollutant Correlations
- Section 14: Summary of Manufacturing Sector Review

The analysis and conclusions presented in this report are those of the authors and should not be interpreted as necessarily reflecting the official policies of the U.S. Environmental Protection Agency.

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The production of the report was ably managed by Carol Rossell, whose patience remained intact through countless drafts and deadlines. Carol was assisted by Sally Webb, Gail Gay, and Deborah Piantoni.

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SECTION 4

HOUSEHOLD SECTOR

SECTION 4

HOUSEHOLD SECTOR

INTRODUCTION

Overview

In one of the first comprehensive assessments of the benefits of air quality improvement, Waddell (1) noted:

> In urban areas some families spend very little as a result of air pollution, but many spend hundreds of dollars more each year than they would need to if the air were clean.

The message is clear, air pollution can be costly to households. The purpose of this section is to estimate some of those costs and thereby estimate the benefits of improved air quality.

In the household sector, there are several ways in which an improvement in air quality can lead to a realization of economic benefits. First, the improvement may affect individuals directly. For example, there is evidence that reductions in ambient concentrations of TSP and SO_2 may have a beneficial effect on the health status of individuals [Lave and Seskin (2)]. Second, there may be certain aesthetic benefits attached to living in an environment with cleaner air (e.g., visibility improvements) [Blank et al. (3)]. Finally, reduced soiling and materials damage to the goods and services consumed by households may result from air quality improvement [Freeman (4)].

This analysis of the household sector focuses on the benefits associated with reductions in soiling and materials damage. In particular, the objective is to provide an assessment of the likely magnitude of the benefits from attainment of the Secondary National Ambient Air Quality Standards (SNAAQS) for TSP and SO_2. The secondary standards have been established to protect the public welfare and are companion to the primary standards for protection of public health.

To date, much of the work on household soiling and materials damage has been devoted to the identification of materials potentially damaged by air pollution [Criteria Document for TSP and SO_2 (5)]. For example, from these studies, it is known that metal surfaces may be subject to corrosion, painted surfaces may need more frequent painting, fibers may deteriorate more rapidly, and various cleaning and maintenance activities may have to be undertaken with greater frequency in order to maintain some desired level of cleanliness.

In this analysis of household soiling and materials damage, the knowledge that particular goods and services may be adversely affected by air pollution is used as a basis for developing an economic model which describes how individuals are likely to adjust to changes in air quality. Specifically, a series of household demand functions are analyzed and statistical methods are used to assess whether ambient concentrations of SO_2 or TSP contribute to the explanation of variation in quantity demanded. For example, an increase in TSP concentrations may lead to an increase in household demand for laundry and cleaning products. The assumption is that such a relationship would reflect an attempt by the household to mitigate adverse effects of TSP through defensive actions. That is, additional laundry and cleaning products are used by households in order to maintain a desired level of household cleanliness.

In the above view, air quality improvement generates benefits because fewer resources are required to produce a given level of cleanliness. In effect, the unit cost of cleanliness is reduced. To the extent that a reduction in ambient concentrations can be linked to a reduction in the unit cost of the service provided by the laundry and cleaning products (i.e., cleanliness), the monetary benefits associated with air quality improvements can be identified.

While this effort is not the first to examine the benefits to households from air quality improvements, the approach adopted is different from those used in earlier studies. Specifically, this analysis examines how households reallocate fixed budgets, given product prices, when air quality improves. The focus is on household decision makers.

There are several advantages to this approach. First, it recognizes that individuals can adjust to the adverse effects of air pollution. As the opening quote in this section indicates, air pollution may affect different households to a different extent. People do make choices, subject to budget and price constraints, and the adjustment possibilities that can be made should be an integral part of any benefits analysis.

Second, by giving additional structure to the benefits model, it is possible to take advantage of the *a priori* restrictions available in conventional models of consumer behavior. Such restrictions are important, as they narrow the range of alternative explanations that might be associated with a particular result.

A third advantage of the household demand approach is that the data required for analysis may be more easily obtained. For example, the major type of economic data required are expenditure and price information for a variety of consumption goods. These data are available from a variety of government sources. While the collection of such data can still present a formidable challenge, the requirements seem much less burdensome than the materials inventory requirements of other approaches to benefits estimation.

Finally, the examination of air quality effects within the context of an economic demand model leads to an analytically correct measure of value. In particular, as noted in Section 2, benefits are correctly defined in terms of the willingness-to-pay concept. In the present case, measures of willingness to pay can be identified from the estimated demand functions.

Objectives of the Study

The main objective of the household sector study is to estimate some of the benefits of the secondary standards. Given this objective, it is helpful to have a set of criteria which allow an informed judgment as to the plausibility of the benefits estimates. The criteria that are important in an evaluation of the model structure and ultimately in the degree of confidence one has in the benefit estimates include:

- The manner in which the household decision model is structured.
- The manner in which air quality variables are introduced into the analysis.
- The sensitivity of results to alternative specifications of functional form.
- The extent to which various assumptions limit the generality of results and/or impose unrealistic constraints on the model structure.

Since each of these criteria may have implications for the benefits estimates to be derived, it is important that some indication of the sensitivity of the benefits estimates to alternative modeling decisions be given. A variety of such checks are presented throughout the analysis reported in this section. While time and resource constraints precluded an exhaustive analysis of the sensitivity of results, the checks undertaken represent an important part of the overall analysis plan.

Quite naturally, before one can be concerned about the plausibility of alternative assumptions within a specific model, there must be some confidence that the general model structure is appropriate for deriving defensible estimates of benefits. This becomes especially important in light of comments by two environmental economists. V. K. Smith (6) summarized his perceptions of environmental benefit analysis techniques as of 1976 in the following way:

> Overall the results of these analyses suggest that the empirical content of environmental economics, while growing, is rather weak. Before we can hope to precisely guide public policy on environmental matters, much greater attention must focus on the modeling and measurement of the benefits and costs of these policies.

More recently, Freeman (7) has voiced similar concern. Freeman lists the following five criteria which he believes a benefits analysis should satisfy.

- The technique must yield measures in monetary value because the objective of the exercise is the determination of values.
- The technique and estimating procedures must be based analytically and empirically on individual behavior and preference, given the utilitarian definition of benefits.
- Benefits estimates must be based on a correctly specified theoretical model of individual behavior and the relationships among economic units.

- The actual measures used in the empirical work should correspond as closely as possible to the variables of the theoretical model.
- Benefit studies must use the empirical techniques appropriate to the theoretical model and the data at hand.

In Freeman's opinion, no benefit study has yet been done which completely satisfies each of these criteria.

Given these comments, the initial work plan developed for this study was conditioned by these challenges to provide a more complete model structure for benefits analysis. Consequently, a second objective of the analysis has been to try to improve on the manner in which such analyses are done. We believe the approach adopted for the present study represents an important step ahead in achieving a more systematic procedure for identifying defensible benefit estimates in a variety of areas.

Scope of Analysis

The discussion of the scope of analysis for the household sector can be conveniently organized in two parts. The first part describes, in general terms, some of the methodological assumptions inherent in the model developed. This is followed by a discussion of the scope of empirical data available for this study.

Methodological Issues--

At the beginning of this section, three ways in which air pollution might affect households were listed. These were direct effects (health), psychic effects (aesthetics), and effects on goods and services demanded by households (soiling and materials damage). This study looks only at the latter type of impact. Given that the primary concern of this study is with the benefits of achieving a secondary standard, conditional on the primary standard being attained and maintained, neglect of direct effects such as health do not appear to be serious. The implicit assumption is that the primary standards are set at a level consistent with the attainment of an optimum for health considerations.

It is more difficult to rationalize the exclusion of the psychic benefits. In fact, the issue takes on importance since researchers have recently suggested that this class of benefits may be relatively large in magnitude [Brookshire _et_ _al_. (8)]. Unfortunately, the household model presented in this section does not identify estimates of pure aesthetic values. Consequently, the reported benefits estimates represent only a partial coverage of air quality benefits in the household sector.*

---

* One way in which some aesthetic valuations might be incorporated in a household decision model is to analyze how leisure activities are influenced by atmospheric visibility conditions. [See, for example, Horst (9).]

The next set of methodological issues involves ways in which households can respond to the damaging effects of air pollution. These adjustments can occur via several channels. They include:

- Moving to a less polluted environment.
- Engaging in maintenance or replacement activities.
- Substituting more resistant products.
- Doing nothing at all.

Ideally, a complete evaluation of economic benefits would be able to incorporate each of these adjustment possibilities within the model framework.

Location Substitutions--

The implication of this adjustment possibility is that individuals no longer view air quality as something beyond their control. Consumers can reduce the costly impacts of air pollution by changing their residence. This location effect can be observed in two economic measures. First, one can hypothesize that air quality effects are capitalized into property values. Thus, in an area of relatively better air quality, the amenities of the site may raise the price of property. The second economic measure that can be affected by the locational attributes of air pollution is wages. In this case, the hypothesis is that jobs in an area with relatively better air quality will be offered at a lower wage rate (relative to a similar job in a "dirty" area) since residents are compensated (non-monetarily) through a better "quality of life" in the area.

In order to incorporate these location effects into the household demand framework described in this section, special assumptions are required. In the case of property values, one can no longer view the price of property as being beyond the control of households. Similarly, for wage rates, one cannot assume that income is fixed. To date in this analysis, a general model that allows for location changes has not been constructed. Consequently, assumptions have been made which permit these location adjustments to be viewed as distinct categories of benefits.

Maintenance and Replacement Activities—

As mentioned earlier, many benefits studies have been concerned with identifying the effect of air pollution on the type and extent of damage to various materials. Given a measure of physical damage, estimates are made of repair or replacement costs. Conceptually, the idea is that if pollution were absent (or lower), these costs of repair/replacement would not have to be undertaken (or would be lower). Thus, the dollar number generated represents the potential cost savings from defensive measures to ameliorate air pollution impacts. Individuals should be willing to pay at least this amount to avoid the deleterious effects of air pollution. Note, however, that this cost-saving measure reflects only the difference in potential expenditures; the amount "at least" that consumers should be willing to pay. True measures of benefits are couched in terms of "maximum" willingness to pay and incorporate the notion of consumers' surplus. This implies that benefits estimates in studies that look only at cost-savings will provide a lower-bound estimate of some true level of benefits. In the present study, since a series of household demand functions is estimated, benefits can be expressed in terms of consumer surplus measures.

Substitution Possibilities--

One means of adjustment that has often been neglected in earlier benefits studies involves the notion of substitution. That is, as air quality improves, an individual has the option of reallocating his expenditures in a different fashion in order to account for expected changes in pollution impacts. The decision for the individual involves choosing that option which he believes will be least costly. The problem this creates for benefit studies is that failure by the analyst to consider the range of adjustment opportunities available to the individual can lead to an understatement of benefits.

One way in which these substitution opportunities can be incorporated into a benefits study is to consider simultaneously the various allocation decisions faced by a consumer. This is done in the current study by analyzing complete systems of demand functions. That is, a series of demand functions for various goods is estimated as a single structural system of equations.

Doing Nothing at All--

While doing nothing at all may not seem very interesting as an analysis issue, it can be an important part of any benefits study. There are at least five ways in which the null response may arise:

- The consumer may not be aware of any damaging effects.
- The consumer feels that the cost of an ameliorative action outweighs the potential benefits to him.
- The consumer may want to adjust to perceived damaging effects but is constrained by available income.
- The observed data may not be conducive to identifying the consumer's response.
- The consumer just doesn't care.

The extent to which the household model addresses each of the "non-response" possibilities is discussed briefly in the following paragraphs.

Imperfect Information--The lack of complete information may have important implications for benefits analysis. This is most likely to be true, however, for the analysis of mortality and morbidity effects. The present study focuses only on the welfare effects underlying a movement from a primary to alternative secondary air quality standards, with a maintained assumption that all health benefits are captured in the attainment and maintenance of the primary standards. It does not seem to be as heroic an assumption that all consumers possess perfect information about "welfare effects".* This is the working assumption in this section.

No Change Warranted--An improvement in air quality may elicit no response from the consumer because he believes that any adjustment on his part will be more costly than the benefit to him. This could be exemplified by the desire of individuals to maintain a habitual pattern of activity. The costs of changing habits are felt to be very high. The degree to which this type of non-response is important will be evident from the statistical analysis.

Constrained Budget--Some consumers may wish to respond to deteriorating levels of air quality but are unable to do so because of budgetary requirements in other categories of expenditures. Although no budget reallocation occurs, there exists a lower level of welfare relative to the case where the budget reallocation is made.

Part of the problem here may be in the orientation of the benefits concept toward willingness to pay. That is, it is implicitly assumed that responsibility rests with the consumers to pay for all adjustments to pollution impacts. An alternative way to look at benefits measures is in terms of "willingness to accept". Under this concept, it is assumed that the property rights to clean air have been assigned to the public. With this criterion, the budget is no longer a constraint on response.

---

* Potential irreversible changes to the ecosystem represent an important effect that may be quantitatively significant yet are areas of great ignorance among most benefits analysts. This type of effect is neglected in the present study.

Which is the more appropriate criterion? From one point of view, the existence of the EPA is in part a signal that the property rights of the air resource belong to the public, so that the willingness to accept concept may be more appropriate. However, in the promulgation of selected environmental regulations, EPA recognizes the conflicting desires of the public in general and the industries or individuals that pollute. Thus, both parties face some degree of restriction in terms of property rights to the air resource. Given this situation and the fact that transactions costs such as information, policing, and contractural costs make it unlikely that an individual would attempt to elicit compensation for soiling or materials damage because of standard violations, operationally, the willingness to pay concept appears to be the more meaningful benefits measure.

In any case, the difference between the two measures will be small if the response to damage requires only a small part of income.* For this project, it would seem reasonable to view the welfare effects as being of this type. Consequently, it is assumed that willingness to pay is the appropriate criterion and that changes in expenditures are small enough so that desired reallocations can be made.

---

* See, for example, Willig (10).

Non-Observable Changes--The third of the "no action" responses involves the idea that some change really does occur, but available data do not allow the researcher to identify changes in welfare. For example, certain types of aesthetic benefits may not be observed because it is difficult to identify meaningful quantitative data. As noted earlier, the present study does not capture such pure aesthetic values.

Non-Respondents--Finally, some individuals may take no action in response to changes in air quality because they really don't care. They make no changes in their allocation decisions because of increases or decreases in pollution levels, and, in a survey situation, they (truthfully) respond that they would never be willing to pay any amount. If air quality improves, they don't clean less and their welfare is not affected even though the average level of cleanliness is higher.

A maintained hypothesis of this study is that better levels of air quality are preferred to less. Thus, the ultimate test of whether such individuals constitute a sizeable portion of the general population will be apparent in the demand relationships estimated and the benefit numbers that are derived.

Scope of Empirical Data--

The economic data used in our analysis of household demand are aggregate data for SMSAs (Standard Metropolitan Statistical Areas).

Expenditure and price data were obtained for approximately 185 consumption items for 24 large SMSAs for the years 1972-73. After aggregation, the dimensionality of the problem was reduced to a more manageable 20 consumption items. Expenditures for goods included in the analysis accounted for about 40 percent of total current consumption expenditures in each of the SMSAs. Among the major categories of goods that have been omitted are recreation and leisure (data limitations) and payments for property services (methodological limitations).

Table 4-1 lists the SMSAs included in the study. In 1976, the population in these SMSAs represented approximately 30 percent of the total population of the country. The benefit estimates reported in

TABLE 4-1. SMSA'S INCLUDED IN THE ANALYSIS

Region I: Northeast

1. Boston
2. Buffalo
3. New York City
4. Philadelphia
5. Pittsburgh

Region II: North Central

1. Chicago
2. Cincinnati
3. Cleveland
4. Detroit
5. Kansas City
6. Milwaukee
7. Minneapolis
8. St. Louis

Region III: South

1. Atlanta
2. Baltimore
3. Dallas
4. Houston
5. Washington, D.C.

Region IV: West

1. Denver
2. Los Angeles
3. San Diego
4. San Francisco
5. Seattle
6. Honolulu

this section relate only to the 24 SMSAs included in the table. In Section 10, estimates are developed for other areas of the country.

Summary of Benefits Estimates

Based on the analysis reported in the following subsections, estimates of the benefits of air quality improvement have been developed. The estimates represent the incremental benefits of attaining Secondary National Ambient Air Quality Standards for SO_2 and TSP by 1987, given that primary standards for the two pollutants are achieved in 1985. Table 4-2 presents the estimates for each of the 24 SMSAs included in the analysis. Entries in the table are discounted present values in 1980 of soiling and materials damage benefits over an infinite time horizon. The estimates assume a 10 percent discount rate and are stated in 1980 dollars. The secondary standards for which the benefit estimates are derived are 24-hour maximum second-high standards for both pollutants (150 $\mu g/m^3$ for TSP and 260 $\mu g/m^3$ for SO_2).

The benefits numbers shown in Table 4-2 are total benefits for each SMSA. On a per-household basis, in the two years of standard attainment, the average level of benefits is approximately $16.25 for TSP and $16.50 for SO_2 (in those areas where the SO_2 Secondary Standard is exceeded). For a unit change in ambient concentrations ($\mu g/m^3$), the per-household benefits are approximately $0.20 and $0.17 for TSP and SO_2, respectively. Regionally, benefits from the

TABLE 4-2. HOUSEHOLD SOILING AND MATERIALS DAMAGE BENEFIT ESTIMATES (discounted present values for 1980 in millions of 1980 dollars)

SMSAs	TSP	SO_2
Region I		
Boston	35.41	*
Buffalo	47.98	37.99
New York	237.05	302.75
Philadelphia	189.71	184.45
Pittsburgh	83.35	74.67
Region Subtotal	593.50	599.86
Region II		
Chicago	254.11	65.45
Cincinnati	21.34	39.88
Cleveland	61.59	52.20
Detroit	172.88	*
Kansas City	39.08	*
Milwaukee	51.92	36.84
Minneapolis	73.95	56.26
St. Louis	85.92	70.06
Region Subtotal	760.79	320.69
Region III		
Atlanta	4.67	*
Baltimore	7.47	*
Dallas	56.00	*
Houston	105.79	*
Washington, DC	152.23	*
Region Subtotal	326.16	*
Region IV		
Denver	112.32	*
Honolulu	*	*
Los Angeles	367.73	*
San Diego	86.61	*
San Francisco	*	*
Seattle	53.48	*
Region Subtotal	620.14	*
Totals	2,300.59	920.55

* Secondary standard not exceeded; therefore no benefits for attainment of standard.

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Region Subtotal	760.79	320.69
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Atlanta	4.67	*
Baltimore	7.47	*
Dallas	56.00	*
Houston	105.79	*
Washington, DC	152.23	*
Region Subtotal	326.16	*
Region IV		
Denver	112.32	*
Honolulu	*	*
Los Angeles	367.73	*
San Diego	86.61	*
San Francisco	*	*
Seattle	53.48	*
Region Subtotal	620.14	*
Totals	2,300.59	920.55

* Secondary standard not exceeded; therefore no benefits for attainment of standard.

reduction of TSP levels are realized in all but two of the SMSAs -- San Francisco and Honolulu. On the other hand, benefits from reductions in the ambient concentrations of SO_2 accrue only to households in the Northeast and North Central regions of the country. Again, we stress that these estimates of benefits cover only the 24 SMSAs included in the analysis. A more detailed description of the way in which these benefit numbers were derived appears in a later part of this section. Extrapolations to the rest of the nation are presented in Section 10.

Section Overview

In the remaining parts of Section 4, a complete framework for performing an air quality benefits analysis in the household sector is developed. Initially, various benefit studies that have been done in the past are reviewed. This review is helpful in establishing the types of benefits that are being analyzed and can also serve as a point of comparison for the plausibility of the benefits numbers derived in the present study. Next, a detailed description of the theoretical model is presented. In this subsection, the structure of the decision process of households and the way in which air pollution might affect household decisions are both examined. This is followed by a description of the available data, and the presentation and evaluation of the empirical results. Given parameter estimates, benefit estimates for achievement of the Secondary National Ambient

Air Quality Standards are calculated. A final subsection briefly summarizes the major findings of the analysis.

SUMMARY OF PREVIOUS BENEFITS STUDIES

The object of an analytically proper air quality benefits analysis is to provide an estimate of the income-equivalent change in welfare for a specified improvement in some measure of air quality. The purpose of this subsection is to summarize the methods that have been used to estimate these values and to assess their success at obtaining meaningful benefits estimates. Additionally, where possible, estimates are presented of the gross benefits identified in these studies. The discussion is taken primarily from Waddell (1) and Freeman (4).

Physical Damage Function Studies

The objective of the damage function approach is to identify objects at risk from air pollution and to develop statistical relationships describing the physical damage that may occur. We have given broad descriptions of the types of effects likely to be observed in the household sector but, in practice, damage function studies focus on particular items within the aggregate classifications. For example, Table 4-3 lists some of the household items that may be susceptible to corrosion or erosion. Similarly, Table 4-4 describes those household activities that may be affected by soiling. Clearly,

TABLE 4-3. HOUSEHOLD MATERIALS SUBJECT TO CORROSION/EROSION

1. Metals
    - a. Steel structures/products*
        - i) Exterior lighting equipment
        - ii) Galvanized roofing, siding, drainage
        - iii) Prefabricated buildings
        - iv) Exterior structural steel
        - v) Exterior gratings, fire escapes
        - vi) Metal doors, windows
        - vii) Chain link fencing
    - b. Aluminum
    - c. Zinc
    - d. Electrical components
2. Building materials**
    - a. Cement and concrete
    - b. Wood
    - c. Building bricks
    - d. Glass
3. Paints (deterioration)+
    - a. Oil-base house paints
    - b. Latex house paints
4. Fibers
    - a. Rugs, draperies
    - b. Furnishings, upholstery

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* Source of steel breakdown is Perl (11), who constructed his table from information in Fink, _et al_. (12).

** Source of building materials breakdown is Barrett and Waddell (13).

+ Breakdown of paint category relies on damage study conducted by Spence, _et al_. (14).

TABLE 4-4. HOUSEHOLD SOILING -- CLEANING AND MAINTENANCE TASKS

1. Outdoor
    a. Painting walls
    b. Painting trim
    c. Washing windows
2. Indoor
    a. Painting walls and ceilings
    b. Wallpapering
    c. Washing walls
    d. Washing windows
    e. Cleaning Venetian blinds

Source: Watson and Jaksch (15), Table 1. The authors note that the tasks described above were drawn from the Booz Allen Hamilton study (16) which included 15 indoor and 12 outdoor tasks. The eight tasks listed here represent those activities that Watson and Jaksch believe to be the most susceptible to particulate soiling.

if total benefit estimates are to be obtained on an item-by-item basis, the compilation of benefits would be an onerous task.

Method Requirements--

The development of benefits numbers for a physical damage function study requires several types of information. First, physical damage functions relating changes in concentrations of a pollutant to some measure of damage must be developed. In general, this requires laboratory experiments which simulate natural environments, but where factors other than air pollution can be kept at predetermined levels.

The second step in a damage function analysis involves a translation of the physical damage function into economic terms. As suggested in the Midwest Institute Report (17), this requires knowledge of four items: information on the distribution of materials; information on the distribution of pollutants; the service life of products in the absence of pollution; and the value of the products or structures using the affected materials.

Not only are these information requirements burdensome, but the process of developing benefits estimates with this type of model implies some strong underlying assumptions and limitations. For example, Waddell [(1), p. 24] mentions that extrapolation of laboratory results to the real world ignores the possibility of nonconstant marginal products, nonlinearities, and problems of aggregation and substitution. Freeman (4) stresses the lack of consideration of consumer adjustments, and the difficulty in assessing the inventory of materials at risk. Despite these drawbacks, physical damage function studies have been the most widely used.

Benefits in the Physical Damage Studies--

One must be extremely cautious when reporting gross benefits estimates from a variety of studies. There are numerous assumptions underlying the development of any particular estimate, so that comparing results of different studies is quite difficult. Among the more prominent aspects to consider are: the assumed base level of air pollution and the direction and magnitude of change; the frequency, averaging time, and collection method of the pollutant; the basis of the economic dollars (e.g., 1970 dollars vs. 1980 dollars); the social rate of discount used in deriving the discounted present value (time stream) of benefits; the statistical sensitivity of the parameters used in calculating benefits; and the methods of extrapolation to the general population (i.e., what is the extent of coverage of the numbers).

As one might imagine, it can be difficult to bring the myriad of physical damage studies into commensurate terms. Fortunately, both Waddell (1) and Freeman (4) present a synthesis of many of these studies.*

In Waddell's case, his best guess estimates of total economic "damage" in 1970 (for 1970 pollution levels) are: $2.2 billion for materials damage, $0.2 billion for vegetation, and $5.8 billion for particulate soiling. We assume that his use of the word "damage" can be taken to mean the total elimination of pollutant impact.** In terms of specific pollutants, damages in 1970 attributable to SO_x are \$5.4 billion, with TSP damages reported as \$5.8 billion. All numbers in Waddell's study are in 1970 dollars.

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* We will not list the many works that went into the summaries of Freeman and Waddell. The reader is referred to these two studies for a complete account of the individual analyses.

** The idea of eliminating pollution is not the purpose of a benefits study. The rule of cost-benefit analysis is that welfare is maximized when marginal benefits equal marginal costs. Under quite reasonable assumptions on the shapes of these curves, it is likely that this optimum will occur with a positive level of pollution.

Freeman's main scenario involves answering the question: What are the benefits with/without a particular piece of legislation? For example, one might compare the actual environmental quality in a given year (Freeman uses 1978) to the environmental quality in the year the legislation was adopted (e.g., the 1970 Clean Air Act). In terms of dollars, Freeman's most reasonable point estimates are \$3.7 billion for materials damage, \$0.5 billion for vegetation, and \$2 billion for soiling, all in 1978 dollars. The materials damage number includes the effects of both TSP and sulfur compounds. The vegetation losses are calculated for sulfur compound pollution, and soiling damage is TSP-specific.

In addition to the numbers available in Waddell and Freeman, SRI (18), in a report recently prepared for the National Commission on Air Quality, published benefit estimates of attaining the secondary national air quality standards for TSP and SO_2. As with Waddell and Freeman, SRI uses earlier studies as the basis for deriving their benefit numbers. For soiling and materials damage, a review of their discussion indicates that SO_2 benefits for materials damage reduction are estimated to be about \$1.8 billion (1980), while TSP benefits of reduced soiling are approximately \$0.65 billion (1980). Several things should be pointed out. First, SRI's benefit numbers were calculated from a baseline of current (1980) levels of ambient air quality to the proposed secondary standards. This contrasts with our approach where the analysis is directed toward measuring the incremental benefits of going from a primary (or current levels if below the primary) to a secondary standard. Second, the materials damage estimates reported by SRI do not distinguish between household materials exposure and the exposure of commercial buildings, manufacturing plants, etc. The analysis in this section is strictly for the household sector. Third, their numbers represent estimates of total national benefits while the results summarized earlier for the present study are valid for only the 24 SMSAs included in our basic analysis. Finally, SRI's benefits numbers appear to be reported in annual terms, whereas our calculations are based on discounted present values.

Indirect-Market Studies

A second method that has been used to assess the economic benefits of air quality improvements is known as the indirect-market approach. Since a market for air quality does not exist, this approach relies on the identification of markets in which changes in air quality may be reflected in production and/or consumption decisions. The household demand model developed in this section is an example of the indirect-market approach. Two other applications of this approach include analyses of residential property markets and the market for labor services.

. In the residential property value studies, the hypothesis is that variations in property values (or rents) can be explained not only by housing attributes, neighborhood characteristics, and availability of services, but also by site-specific air pollutant concentrations. *A priori*, the presumption is that higher levels of air pollution lead to relatively lower residential property values, all other housing attributes being the same.

While there have been many empirical studies of property value differentials, this type of analysis is not well-suited to the problem of estimating non-health benefits of the secondary standards. This is because property values are likely to reflect all perceived, at home, effects of air pollution. Consequently, in addition to coverage of soiling and materials damage effects implicit for a particular site, benefits estimates derived from property value studies may also include values for health and aesthetic benefits. Since it is difficult to identify the separate influences of the various benefit types, estimates based on property value differentials are likely to be larger than those reported for the household demand model developed in this section.

However, this relationship can provide useful information. In particular, a benefit estimate calculated from an analysis of residential property values may be interpreted as an upper-bound plausibility check on the household demand model benefits. For this reason, a review and synthesis of the literature on property value analysis was undertaken in this study, and benefits estimates were obtained using scenarios consistent with those used in other sections of this report. The results of this analysis are reported in Section 5.

The second application of the indirect-market approach mentioned above relates to the market for labor services. In this case, the underlying hypothesis is that wage rate variations can be explained by attributes of the individual, characteristics of the job, and location-specific amenities such as environmental quality. Here, the presumption is that jobs in an area with relatively better air quality will be offered at a lower wage rate than similar jobs in a more polluted area.

A benefits analysis based on wage rate variations is likely to encompass a variety of benefit types, including health and aesthetic benefits. Thus, as in the case of property values, it may be difficult to identify non-health benefits directly. As before, estimates from the wage rate approach become useful as cross-checks on the plausibility of the household demand model estimates. The results of an analysis of wage rates is presented in Section 6.

Other Benefits Approaches

For the sake of completeness, several other techniques that have been suggested for benefits analysis are listed below. These approaches can, in general, be classified as non-market studies. No discussion is offered, however, and the interested reader is referred to Waddell (1) for further elaboration. These other techniques include:

- Opinion surveys of air pollution sufferers.
- Litigation surveys.
- Political expressions of social choice.
- The Delphi method.

Overall Summary of Previous Air Quality Benefits Studies

In this subsection, some of the ways analysts have approached the estimation of economic benefits have been discussed. To date, the most popular methodology has involved an examination of the relationship between pollution and the physical damage to materials thought to be at risk from exposure. These studies provide a direct link between air pollution and the objects valued by human beings. While the studies are important for determining the type and extent of pollution effects for specific materials, aggregation to more complete inventories of materials imposes data difficulties.

Economists have found fault with these studies both for data reasons, and more importantly, for conceptual reasons. In particular, they point out that a model that does not account for the behavior of man and his interaction with the environment cannot provide analytically correct measures of welfare change. One outgrowth of this observation has been the development of indirect-market studies, in which pollution is presumed to play a role in the supply and demand decisions in various economic markets. Two markets that have received considerable attention are the property market and the labor services market. In these studies, the location-specific attribute of air pollution is highlighted and assumptions are introduced which permit the analyst to examine locational variations in demand and supply due to air quality differences.

While the model developed in this section is also of the indirect-market type, the adjustment mechanisms assumed to be available to households are different. In particular, location decisions are viewed as having been made, and reallocations in demand are assumed to reflect short-run adjustments to changing pollution levels. This model is discussed fully in the next subsection.

MODEL DEVELOPMENT

It was noted earlier that the manner in which the household decision process is modeled is one of the important criteria for judging the plausibility of the analysis. In this section, the model that will be used to characterize household decisions is described in detail.

Figure 4-1 outlines the major components of the decision process. The initial decision facing the household is the allocation of a fixed

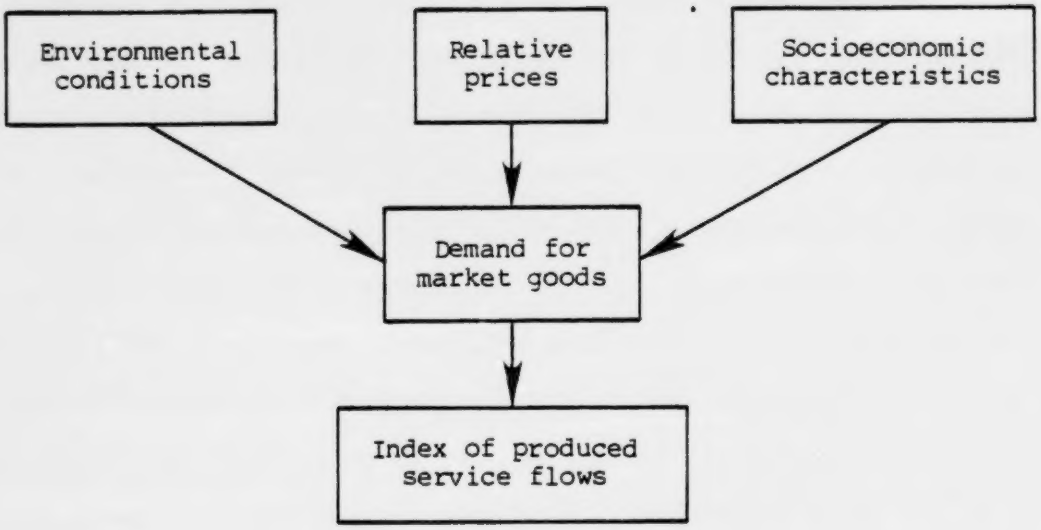

Figure 4-1. Household decision process.

budget among the many market goods that may be purchased. In order to determine these "demands", various factors that are beyond the control of the household must be taken into account. In particular, the relative prices of the goods, income, and various demographic factors all help to shape the pattern of household demand. Furthermore, environmental conditions such as ambient concentrations may also influence the demand for certain goods. For example, the demand for detergents or other cleaning products may be sensitive to the level of TSP concentrations.

Once the allocation decision has been made, conditional on the factors mentioned above, the decision-making role of the household is essentially complete. However, there is a natural extension to the process that is important for benefits analysis.

The idea behind the extension is that items like detergents are not demanded for their own sake, but rather for the services they provide. Thus, it may be instructive to view the demand for detergents as a derived demand based on a more fundamental consumer demand for cleanliness. Viewed in this way, the allocation decision made by households with respect to detergents and other cleaning items is consistent with attaining a particular level of household cleanliness. Furthermore, the role of air pollution is clear. In particular, air pollution increases the cost of cleanliness by increasing the quantity of detergents and other cleaning items required to obtain a unit of cleanliness. Conversely, a reduction in air pollution can lead to a reduction in the unit cost for cleanliness, and consequently economic benefits are generated.

The underlying relationship between services such as cleanliness and market goods is also portrayed in Figure 4-1. While households are not required to make any new allocation decisions in order to identify the index of service flows, the structure of the link between the service flows and market demands is crucial. In fact, the discussion of how this link can be established in a consistent fashion is a major concern of this subsection.

The nature of this link is formalized by adopting the assumption that the market goods demanded by households can be grouped naturally into a series of categories (i.e., final demand service flows) such that the demands for goods in one group are independent of the demands for goods in another group. Thus, all items that serve to promote household cleanliness can be grouped together, and because of the independence assumption, it is possible to analyze budget decisions for these goods in a decentralized manner. Furthermore, given appropriate mathematical conditions on functional structure, a well-defined index for a particular service flow can be constructed solely from the budgeting information available in the group corresponding to the service flow of interest.

The model described above is structured to deal directly with household adjustments to air quality changes. The focus is on the value households place on certain activities rather than specific pollution-induced damage. A physical damage function between pollution and objects that may be damaged is not included in the analysis. Instead, pollution enters the model as a proxy for damage. It is not imperative that the type or extent of physical damage is identified explicitly. The knowledge that is required is the value household decision makers attach to activities or services that may be sensitive to air quality changes.

The plan of this subsection is as follows. First, the consumer's decision problem is described in terms of an optimization model. Specifically, the notion of a utility function is introduced and the relationship between the utility function of the consumer and his demands for various goods and services is developed in a nonrigorous fashion. Following this discussion, the procedures underlying the development of the link between market demands and household services is presented. In particular, it will be demonstrated that if households engage in groups of activities which can be viewed as independent from one another, then it is convenient to construct a decentralized decision problem that reflects a two-stage budgeting problem.

Given the general structure of the theoretical model, the remaining subsections focus on specific assumptions required for an empirical study of air quality benefits. The discussion covers the concepts of aggregation and separability; feasible alternative functional forms for the utility function; the manner in which environmental and demographic variables can be introduced into the analysis; deviations from the assumptions of the standard utility maximization problem; and a discussion of the hypotheses to be tested. The section concludes with a brief summary of the advantages and disadvantages of the developed model.

Utility Maximization

In simplest terms, a utility function can be defined as a function which measures the level of satisfaction associated with a particular bundle of goods.* Utility theory can be utilized with assumptions of different degrees of generality. The assumptions adopted for the present study require only that the utility function represents an ordinal index of preferences. That is, the utility function can be used to rank one bundle of goods as being more preferred, less preferred, or indifferent to an alternative bundle of goods, but it does not imply anything about the intensity of preferences.

---

* Our presentation of consumer choice theory relies on the calculus as a tool of analysis. Modern treatments of the consumer's problem also use concepts from set theory to characterize preferences. See, for example, Varian (19).

If there are only two goods in the world, one can write the utility function as:

$$U = U(x_1, x_2) \tag{4.1}$$

where U is the utility index and x_i is the i^{th} good that can be purchased by the consumer. If another combination of the goods x_1 and x_2 [denoted as (x_1^2, x_2^2)] is preferred by the consumer, then the utility index associated with (x_1^2, x_2^2) is greater than the utility index associated with the bundle (x_1, x_2). The goal of the consumer is to achieve as high a level of utility as possible. Clearly, if more of a good implies higher levels of utility, then the consumer would always opt for more of the good unless a constraint were placed on his choices.* In fact, people are constrained in their choices among commodities by the level of their income. In the simplest textbook version of the utility maximization model the maintained assumptions are that the consumer views his income as well as the prices of the products he can purchase as given. Furthermore, it is generally assumed that he spends his entire fixed income on the available goods.

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* In this general description of utility functions, we have omitted many details of conditions that are required if consumer preferences are to be adequately and consistently portrayed. A description of these conditions can be found in a microeconomic textbook such as Henderson and Quandt (20).

Thus, we can write a more complete version of the consumer's decision problem as:

$$\max_{x_i} U = U(x_1, x_2) \tag{4.2}$$

$$\text{Subject to} \quad p_1x_1 + p_2x_2 = M$$

where p_i is the price of the i^{th} good, M is fixed income, and x_i, U are as defined previously. Equation (4.2) states that the decision problem of the consumer is to find that combination of goods x_1 and x_2 which maximizes his utility subject to the budget constraint imposed by his available income.

Before we present a graphical interpretation of the consumer's decision problem, it is helpful to consider another concept called an indifference curve. As the name implies, this curve represents a locus of combinations of the two goods, such that the consumer finds the combinations of goods equally desirable. In terms of his utility index, he realizes the same level of utility from any of the combinations, and hence is indifferent to which is selected. Indifference curves corresponding to levels of utility U^1, U^2, U^3 are shown in

Figure 4-2 where $U^3 > U^2 > U^1$.* In this figure, the quantity of good x_1 is on the vertical axis, while the quantity of good x_2 is on the horizontal axis. The budget constraint is represented by the downward sloping line AC. Thus, any combination of goods inside the triangular area ACO can be purchased by the consumer, while a combination of x_1, x_2 to the right of the budget line is unattainable for the consumer given current prices and income. In the figure, the consumer

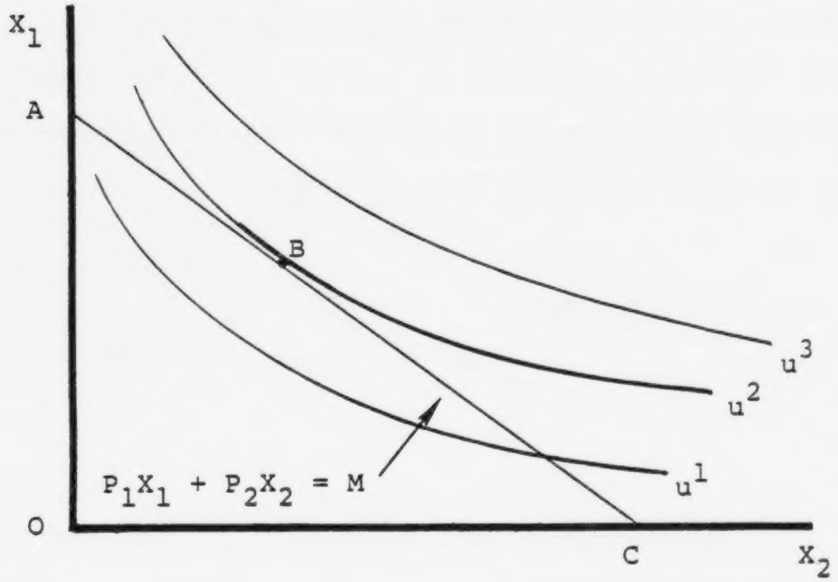

Figure 4-2. The consumer's optimum.

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* The curvature properties of the indifference curve are of course very important. Among the assumptions on the utility function is one of strict quasi-concavity which will guarantee convex to the origin indifference curves like the ones depicted in Figure 4-1. With indifference curves of this shape, consumers must give up some of one good for each additional unit they gain of another good if they are to stay on the same indifference curve (i.e., at the same level of utility).

maximizes his utility by obtaining the combination of x_1 and x_2 represented by point B. With this combination, he achieves utility level U^2. While utility level U^3 is greater than U^2, the former utility level is not attainable.

Demand Functions

The mathematical problem represented by Equation (4.2) can be solved for the utility maximizing values of x_1, x_2. The solution of the problem results in demand functions for x_1 and x_2. These functions depend on variables outside of the individual's control. These are called exogenous variables. In the present case, the exogenous variables are the prices and income.

$$x_1 = f^1(p_1, p_2, M) \tag{4.3}$$

$$x_2 = f^2(p_1, p_2, M) \tag{4.4}$$

The demand functions portray the choices made by households given prices and a fixed budget. Graphically, demand curves can be illustrated as shown in Figure 4-3. In the diagram, the price of the good is on the vertical axis while the quantity demanded is on the horizontal axis.* For a given demand curve, other prices and the

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* The placement of price on the vertical axis is counter to the mathematical representation in Equations (4.3) and (4.4) where price is an independent variable. However, this has become the standard way in which economists draw demand curves. In effect, Figure 4-3 can be thought of as portraying an "inverse" demand curve.

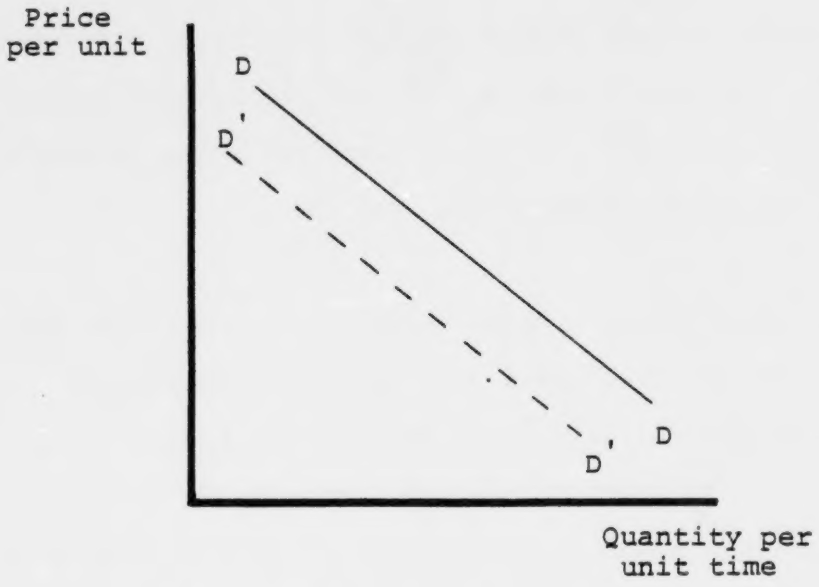

Figure 4-3. Demand curve.

budget (income) are assumed to be constant. The solid line DD is the demand curve relating price and quantity for specific levels of these other variables. If one or more of these other parameters changes, the demand curve can shift. An inward shift is shown in the figure as the dotted line D'D'. This shift might occur because of a price change in a good related to the good for which the demand curve is derived. For example, suppose DD represents the demand for butter. Then if the price of margarine decreases relative to the price of butter, less butter will be demanded at each price.

Several things can be highlighted from the derivation of the demand functions shown in Equations (4.3) and (4.4). First, for a specific utility function form, it may be possible to define a demand curve. This intimate connection between utility and demand makes it essential that the demand curves we estimate are plausible in the sense that the utility function from which the curves are derived conforms to certain mathematical conditions.*

The second point is that Equations (4.3) and (4.4) imply a series of restrictions which lead to a system of equations. This occurs because the prices for both goods appear in each of the demand equations. Thus, in order to take into account the information provided by all the parameters of the model, the pair of equations should be estimated as a single structural model.

When there are many goods involved in the analysis, it is impractical to assume that consumers consider all of these decisions simultaneously. Instead, it may be more meaningful to assume that thre is a natural decomposition of household activities into independent groups which characterize various household activities (e.g., household cleaning). The budgeting (allocation) decision of the consumer would then be based only on the characteristics (prices, etc.) associated with each of the individual activities.

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* These conditions require that consumers' preferences are transitive, reflexive, complete, nondecreasing, continuous, and convex. Thus, the utility function is nondecreasing, continuous, and quasi-concave. (It is also assumed that the utility function is twice differentiable.) For a discussion of these "regularity" conditions, see Henderson and Quandt (20), Chapter 2.

The final point concerns those factors which can lead to reallocations between goods. As Equations (4.3) and (4.4) indicate, demand depends on prices and income. Thus, for given tastes (consumer preferences), reallocations will occur when relative prices change (i.e., the slope of the budget constraint in Figure 4-2 changes), or when income is changed (i.e., the budget line in Figure 4-2 shifts). Of major interest here, however, is the role played by air quality in reallocation decisions. As currently written, Equations (4.3) and (4.4) have nothing to say about air quality.

Demand Functions and Air Quality--

If air quality were a private good with a well-defined market price, then it could be treated as one of the x_i. However, air quality is a predominantly public good rather than a private good, and generally no market price for air quality exists.* In order to determine people's demand or willingness to pay for specific levels of air quality, modifications to the above model are required.

Mäler (21) lists four alternatives that may be used to identify the willingness to pay for environmental services:

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* A public good can be defined as a good which can be "consumed" by one person without reducing the consumption possibilities of the good by another person, and for which exclusions from consumption are impossible.

- Asking consumers how much they are willing to pay for some increase in the supply of an environmental service.*
- Voting on the supply of an environmental service.**
- Indirect methods, based on relations between private goods and environmental services.+
- Estimating the physical damage from residuals discharge and evaluating this damage by using market prices.++

The approach proposed in this section is consistent with the third alternative mentioned by Mäler. Basically, measures of ambient air quality are incorporated into the demand functions of specific private goods as additional explanatory factors, the hypothesis being that changes in the level of air quality shift demand for the private goods. For example, if air quality improves, the demand for laundry and cleaning products would be expected to shift inward, so that at a given price with all other factors held constant, an individual would demand fewer units of laundry and cleaning products per unit time.

In equation form, one can write:

$$x_i = f^i(p_1, p_2, AP, M) \tag{4.5}$$

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* An example of this type of study can be found in Randall _et al_. (22).

** An example of this type of study can be found in Fischel (23).

+ An example of this type of study can be found in Blank _et al_. (3).

++ Examples of studies of this type are available in drafts of the Criteria Document (5).

where AP is the ambient concentration of a particular pollutant, and the other variables are as defined previously. In terms of the laundry and cleaning products example, one would expect the partial derivative of x_i with respect to the measure of air pollution to be positive. This occurs because most cleaning expenditures made by households in response to higher levels of air pollution can be viewed as defensive expenditures.

Overview of Service Flow Indices

The discussion to this point has focused on the manner in which the consumer is assumed to allocate his budget among market goods. The topics that have been considered are pertinent to the decision process portrayed in the top half of Figure 4-1. Among the issues covered thus far, one of special interest involves the observation that it is reasonable to consider that consumer budgeting decisions are decentralized. That is, market goods that contribute to a specific household activity (e.g., household cleaning) may be grouped together.

In the following discussion, this decomposition is used to describe a process for establishing a consistent link between market goods and indices of service flow. This is the relation identified in the bottom part of Figure 4-1. The framework required to formalize this link can be described heuristically, as follows. Rather than market purchased goods like detergents yielding utility directly, it is the household cleanliness services they provide from which the consumer derives utility. The demand for a good like detergents is more properly viewed as a derived demand based on a more fundamental consumer demand for cleanliness. The grouping of the derived demands into classes of activities implies that something is known about the factors which help to "produce" the utility-generating service flows like cleanliness. What remains to be established is the exact structure of this relationship and the role of air pollution in the linkage.

With respect to air pollution, one can hypothesize that an improvement in air quality would lead to a lower implicit price for cleanliness in the sense that it becomes easier to attain the same level of cleanliness with decreased pollution levels. If such an effect on the implicit price (cost) of cleanliness is observed, then the change in price can be used in a meaningful way to identify the economic welfare change associated with air quality improvements. The shaded area in Figure 4-4 illustrates this welfare change. The welfare gain can be split into two parts. First, the consumer reduces expenditures on the Q_1 units of cleanliness originally demanded by the amount P_1ABP_2. Then, because of the reduced price of cleanliness, $Q_2 - Q_1$ additional units of cleanliness are obtained.

With respect to the structure of the link between groups of market goods and the service flow indices, a general way of viewing

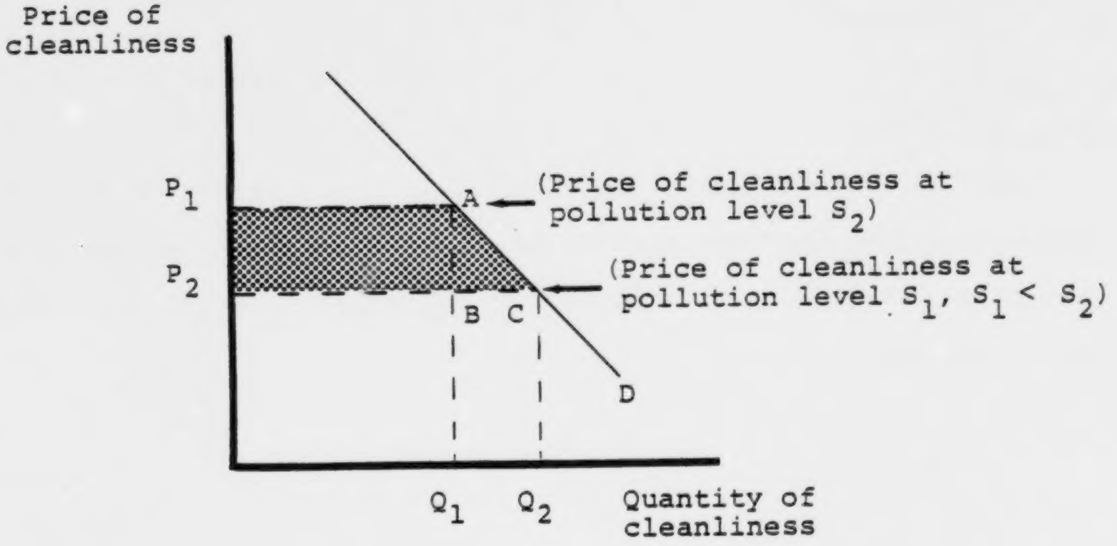

Figure 4-4. Welfare change from air quality improvement.

this relationship can be observed in the concept of a household production function.

In the economics literature, the idea of household production has been described in the following way.*

> The household purchases "goods" on the market and combines them with time in a "household production function" to produce "commodities". These commodities, rather than the goods, are the arguments of the household's utility

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* The concept of household production functions is generally traced to Lancaster (24), Becker (25), and Muth (26), with subsequent refinements and clarifications discussed by such as Pollak and Wachter (27), Muellbauer (28), and Hori (29). This approach has also been used by Griliches (30) and others to analyze questions of quality differences in products.

> function; market goods and time are not desired for their own sake, but only as inputs into the production of "commodities".
>
> [Pollak and Wachter (27)]

If Z is cleanliness, A is air quality, X is a vector of private goods that help achieve cleanliness, and T is the time spent in producing cleanliness, the household's production function for Z can be written as:

$$Z = G(A, X, T) \tag{4.6}$$

Equation (4.6) establishes a relationship between the various arguments and the unobserved output Z. While we do not have a quantitative measure for Z, if it is possible to add structure to the character of the relationships among the variables on the right-hand side of (4.6), we can gain insights into the manner in which individuals adjust to changes in pollution. This structure is developed below in the context of a two-stage budgeting decision.

Two-Stage Consumer Budgeting

A way of formalizing the decision process of the consumer that is consistent with the discussion to this point is to assume that consumers budget their expenditures in stages. First, consumers are assumed to allocate their total income (expenditure) among broadly defined categories such as food and clothing, and given the (optimal) share of expenditure to each broad category, next decide upon the allocation of category expenditure to each of the goods within the group.

In equation form, the two stages can be written as:

Stage 1.

$$\max_{Z_i} U = U(Z_1, Z_2, \ldots, Z_n) \tag{4.7}$$

$$\text{Subject to} \quad R_1Z_1 + R_2Z_2 + \ldots + R_nZ_n = M$$

where Z_i is the i^{th} aggregate good

U is the utility function for the broad (aggregate) group

M is total money income (expenditure)

R_i is the price index for the i^{th} aggregate good.

The solution to Equation (4.7) is a system of demand equations which define optimal levels for the Z_i $(=Z_i^*)$. Multiplication of Z_i^* by R_i then yields the optimal expenditure for group i, M_i.

Given M_i, we can then proceed to Stage 2.

Stage 2.

$$\max_{X_{ij}} Z_i = Z_i(X_{i1}, \ldots, X_{ir}) \qquad i = 1, \ldots, n \qquad (4.8)$$

$$\text{Subject to} \quad P_{i1}X_{i1} + \ldots + P_{ir}X_{ir} = M_i$$

where X_{ij} is the jth good in the ith aggregate group.

Z_i is an aggregate service flow defined by the subfunction of the X_{ij}.

M_i is the money allocated to the disaggregate stage from the first stage decision.

P_{ij} is the price of the jth disaggregate good that appears in the ith aggregate group.

The two-stage budgeting decision presented above makes the implicit assumption that something is known about the way people combine various goods, the X_{ij}, in order to obtain a particular flow of services, the Z_i. Although the structure of the process is formally akin to the utility maximization technique described earlier, the important aspect of Equation (4.8) for the present study is that the functions of the X_{ij} variables represent a household production-like process, where the two-stage budgeting model adds the structure necessary to define an aggregate index of the Z_i. In effect, the subfunctions of the X_{ij} can be thought of as commodity indices for each of the Z_i services.

Note that the assumptions made earlier with respect to the decomposition of goods into classes of activities fits in naturally with the two-stage budgeting framework. In particular, Equations (4.7) and (4.8) describe an allocation process in which expenditure decisions are made first among broad categories using information on only total expenditures and price indices for each broad category. Then intracategory allocations are determined with information on only prices for the specific goods within the broad category. For example, none of the P_{ij}'s appear in the Stage 1 analysis and no P_{kj} appears in the Z_i utility maximization problems where $k \neq i$. Basically, the decision problem of the consumer is structured so that each of the broad categories of service flows is composed of a group of private market goods that is common to the aggregate activity.

Using the definitions of terms in Equations (4.7) and (4.8), each Z_i can be viewed as a quantity index of private goods. If there are only two classes of aggregate service flows and five private goods, one might write:

$$\begin{aligned} Z_1 &= f_1(X_1, X_2, X_3) \\ Z_2 &= f_2(X_4, X_5) \end{aligned} \qquad (4.9)$$

Note that an X_i may appear in only one "aggregate" function. This non-jointness property is necessary for the two-stage optimization problem to be valid.

In terms of the function U of Equation (4.7), this means that one can write:

$$U = U\left(f_1(X_1, X_2, X_3), f_2(X_4, X_5)\right)$$

In addition to the index Z_i price indices R_i can also be defined such that:

$$R_i = g_i(P_{i1}, \dots, P_{ir}) \quad ,$$

or in terms of the example:

$$\begin{aligned} R_1 &= g_1(P_1, P_2, P_3) \\ R_2 &= g_2(P_4, P_5) \end{aligned} \tag{4.10}$$

Given these definitions of aggregate price and quantity indices and the description of the two-stage budgeting procedure, it is desirable for the procedure to be consistent in the sense that solution of the consumers' allocation problem in two stages leads to the same solution vectors for the private good quantities (the X_i) as would be obtained if one were to solve the larger (in terms of number of parameters) allocation problem:

$$\text{Max } U\big(f_1(X_1, X_2, X_3), f_2(X_4, X_5)\big) \tag{4.11}$$

$$\text{Subject to} \quad \sum_{1}^{5} P_i X_i = M$$

In order for this process to take place in a consistent fashion, Strotz (31) and Gorman (32) have shown that the first-stage functions must be weakly separable and that each of the subfunctions [see Equation (4.9)] must be homothetic. Furthermore, these conditions are necessary and sufficient. Before continuing with the outline of the consumer's decision problem, a discussion of the terms separable and homothetic is presented.

Separability--

Formally, one can define a group of goods to be (weakly) separable if and only if the marginal rate of substitution between any two goods in the group is independent of the quantity of any good outside the group. With the marginal rate of substitution defined as the ratio of marginal utilities,* this definition can be represented mathematically as:

$$\frac{\partial}{\partial X_4}\left(\frac{\partial U/\partial X_1}{\partial U/\partial X_2}\right) = 0 \tag{4.12}$$

---

* Recall that marginal utility is defined as the partial derivative of the utility function with respect to the good in question.

where the definition has been particularized to the division of goods suggested by Equation (4.9). Green (33) provides a proof that satisfaction of this condition allows one to write the utility function

$$U = U(X_1, X_2, X_3, X_4, X_5) \qquad (4.13)$$

like the one shown in Equation (4.11).

The reason that the concept of separability is so important to economic analysis is that it places specific restrictions on the forms of the demand functions to be estimated.* In Stage 2 of the two-stage budgeting problem, by using the notion of separability as a maintained hypothesis, one can look at the system of demand equations for such quasi-disaggregate food items as meat, vegetables, fruits, and dairy products without reference to non-food items like men's pants. Thus, separability is consistent with the notion that households naturally group goods into "separable" classes of activities. Furthermore, at the Stage 1 aggregate level, the concept of separability provides a rationale for limiting the range of expenditure categories represented by the Z_i. An example relevant to the present study comes to mind. In this study, we ignore labor-leisure decisions of the consumer. We take income as fixed, and assume that recreational (leisure) expenditures are separable from the group of consumption categories that are examined. This is not to say that recreational plans are not affected by the level of air quality. Rather, the assumption is made that changes in air quality do not cause reallocations between consumption and leisure activities. Separability provides the theoretical basis for making this division.

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* Note that separability also is important for the household production framework discussed earlier. See Muth (27).

There are other types of separability besides the weak separability definition given here. For our purposes, however, weak separability meets our needs. There are few accessible treatments of separability in the economics literature, but one source is Deaton and Muellbauer (34).*

Separability is also a useful concept in the construction of consistent price and quantity indices. Recalling the first stage of the two-stage budgeting problem [Equation (4.7)], one might legitimately ask how quantity indices (Z_i) and price indices (R_i) are obtained for the aggregate service flows. The key to answering this question involves specific mathematical assumptions for the subfunctions of the budgeting process. In particular, these subfunctions must be homogeneous of degree one.

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* The mathematically sophisticated reader can find detailed descriptions of separability and functional structure in Blackorby, _et_ _al_. (35).

Homotheticity and Homogeneity--

A function f(x) is defined to be homothetic if there exists a homogeneous function of degree one such that

$$f(x) = \phi\big(g(x)\big) \qquad (4.14)$$

where ϕ is a monotonic transformation. An implication of homotheticity is that a ray through the origin (in goods space) will cut all indifference curves at a point of equal slope. This implies, in turn, that there are unitary income elasticities, and that a change in demand due to a change in price will be independent of income.

Homogeneous functions are a special case of homothetic functions. In particular, a scalar-valued function f(x) is defined to be homogeneous of degree α if it satisfies the relationship

$$f(tx) = t^{\alpha}f(x) \quad .$$

In the discussion below on consistent aggregation, one of the conditions required for the existence of a consistent aggregate price index is that the subfunctions of market goods be homogeneous of degree one.

Consistent Aggregation--

The notion of separability has been discussed in the context of reducing the dimensionality of the budgeting problem by adopting assumptions consistent with the grouping of goods into classes of activities. The use of separability in forming a consistent link between these groups of goods and the more general classes of service flows is intimately related to the concept of price aggregation.

The easiest way to understand aggregation across goods is to construct an example. In particular, consider the aggregate commodity "food". Figure 4-5 provides a schematic representation of one of the branches that describes food in the overall "utility tree".* What the

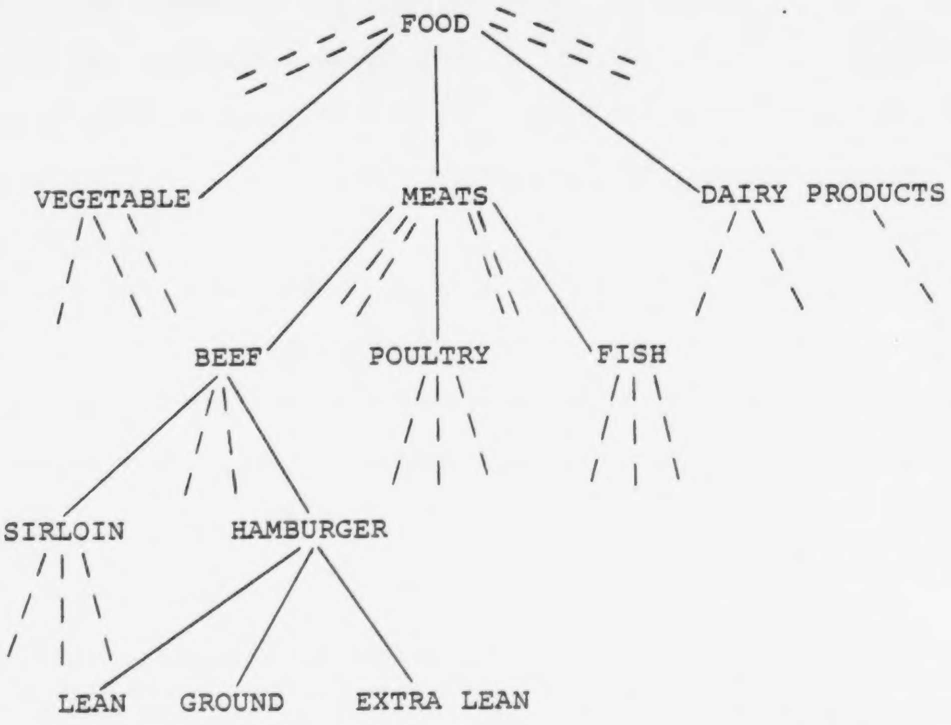

Figure 4-5. Schematic of a "utility branch".

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* The concept of a utility tree is traced to Strotz (31), while Brown and Heien (36) have discussed "branches" of the tree.

tree shows is that goods purchased in the market place are very individualistic items. In fact, one could define a very specific good at a specific point in time as being a fundamentally different consumption good from that same good at a slightly later time. This, of course, would not be practical. The intuitive test suggested by economists is that if one good is perceived as being a perfect substitute for another good, then for purposes of analysis, nothing is lost by assuming that they are the same good. Thus, in terms of information needs for the budgeting procedure, one might expect to obtain the most disaggregated data at the level of "hamburger", "sirloin", etc. Implicitly, it is assumed that different qualities of hamburger are reflected as part of an average price obtained from the sample of observations for hamburger, and that relative prices among qualities of hamburger remain constant.*

The question to be answered here is how does one move from hamburger to beef to meats to a price and quantity index for food? The theory of index numbers can be extremely complicated, and we save the description of the actual process of aggregation for the DATA section.

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* This latter point is known as the Composite Commodity Theorem of Hicks. Note that if one believes the theorem holds for higher levels of aggregation (i.e., that relative prices did not change), then one could form an aggregate quantity index on the basis of price proportionality alone. Similarly, if one assumes that goods in a group are always consumed in fixed proportions, then a consistent price index for the group can be formed. The form of aggregation we adopt, based on the notion of functional separability, does not require these assumptions.

In this section of technical details, further discussion of aggregation is limited to a theorem concerning the existence of an aggregate price index.

The theorem is taken from Blackorby, et al. (37). In the notation used earlier, the theorem can be stated:

If the utility function U [see Equation (4.7)] is weakly separable, then there exist price indices

$$R_i = g_i(P_i) \quad \text{for all } i \qquad \text{[see Equation (4.10)]}$$

such that $R_i Z_i^* = M_i$

which implies that

$$\Sigma R_i Z_i^* = M$$

where $Z_i = G_i[f_i(X_i)] \equiv h_i(X_i)$ [see Equation (4.9)]

and G_i is a monotonic transformation of f_i

Z_i^* is the optimal value of Z_i obtained by placing the solution values of X_i in Stage 2 into the quantity index represented by Equation (4.9);

if and only if

> each of the subfunctions $f_i(X_i)$ is homothetic. This implies that we want to choose G_i such that $h_i(X_i)$ is homogeneous of degree one.*

The various concepts underlined in the statement of the theorem are items that have been discussed in previous pages of this section.

If the conditions of the theorem are satisfied, aggregate price and quantity indices can be defined, and the two-stage budgeting problem takes on real meaning. Thus, demand relationships can be estimated and the link between the two budgeting stages established. Naturally, of primary concern here is the effect of air quality changes on demand. Earlier, it was noted that air quality could be entered as a shift parameter in the demand equation for disaggregate (market) goods. This approach is retained here and formalized in a later part of this section. There is also a question as to how air quality might affect the demand for the aggregate service flows. There are two possibilities. As with the disaggregate goods, air quality can serve as a shift parameter to the broad categories of goods. Alternatively, given the definition of the aggregate price index, changes in air quality can impact the level of the index.

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* A proof of this theorem appears in Blackorby, et al. (37).

This suggests the following procedure for identifying the effects of air quality changes on allocation decisions. First, demand systems for the disaggregate stage are estimated. With the assumption of weak separability, there will be as many disaggregate systems as there are categories of aggregate service flows. Furthermore, for some of these demand systems, air quality may be a statistically significant explanatory variable.

Given the estimated parameters of a particular disaggregate demand system, it is possible to use the theorem stated above to define price/quantity indices for the associated aggregate good. In particular, for homothetic disaggregate stage subfunctions, the marginal budget shares can be used to form a subfunction which satisfies the homogeneity requirements of the theorem. Since this function depends on the (optimal) quantities demanded of the goods in a particular disaggregate demand system, it also depends indirectly on the level of air quality. Thus, air quality effects will show up as implicit shifters to the price index for an aggregate service flow. The interpretation is that reduced levels of air pollution reduce the cost of obtaining a unit of an aggregate service flow such as cleanliness.

The important point to recognize is that the marginal budget shares, which are used to ensure the linear homogeneity of the quantity index, can be obtained from the solution to the Stage 2 decision.

This model forms the basis for the estimation procedures used in this study. However, certain topics must be considered before the various demand systems are actually estimated. These topics include a discussion of alternative functional forms; the manner in which air quality information is included in the analysis; restrictions to the general model that are specific to an air quality benefits model; and a brief discussion of hypotheses to be tested.

Alternative Functional Forms

Earlier in this section, it was mentioned that demand systems should be plausible in the sense that they can be derived from a utility function which meets various "regularity" conditions. This can be viewed in two ways. On the one hand, various forms for demand systems could be estimated first, and if the "Slutsky Conditions" are met, the "integrability" conditions could be used to define the utility function up to a constant of integration.* This process can be extremely messy.

Alternatively, one can assume a specific form for the utility function, recognizing the implied assumptions for the associated demand systems, and proceed to the estimation of these systems.** This is the approach adopted here.

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* See Samuelson (38) for a discussion of integrability, and Mäler (21) for an example application of the process described here.

** For a summary of the theoretical constraints of demand systems, see the review article by Brown and Deaton (39) or Barten (40).

Consumer preferences have been characterized by a wide variety of models in the economics literature. Among those most frequently used are:

- Cobb-Douglas.
- Linear Expenditure System [Pollak and Wales (41)].
- The Translog form [Christensen, Jorgensen, Lau (42)].
- Quadratic Expenditure System [Pollak and Wales (43)].
- Rotterdam System [Theil (44)] (especially Chapters 6 and 7).
- Linear Logarithmic from the indirect translog with homogeneity restrictions [Lau, Lin and Yotopoulos (45)].

The discussion of choice of functional forms is left to the ESTIMATION section. It should be pointed out, however, that two forms are chosen for estimation in order to provide some indication of the sensitivity of the results to alternative structural specifications. The two forms are the linear expenditure system (LES) and the homogeneous translog system (HTL).

Inclusion of Environmental/Demographic (E/D) Variables

The model structure for the two-stage budgeting procedure described in Equations (4.7) and (4.8) is conspicuous in its absence of an air quality variable. In two recent articles, Pollak and Wales (41,43) have proposed two ways for including exogenous environmental/ demographic effects in systems of demand equations. While the application of their research has been specific to the linear expenditure system (LES), the quadratic expenditure system (QES), and various forms of the translog system, the concepts embodied in translating and scaling are appropriate for any plausible demand system.*

Translating--

As described in Pollak and Wales (43), translating involves introducing n translation parameters ($d_1, \ldots, d_n$) into an n-variable demand system, such that these parameters and only these parameters depend on the environmental/demographic (E/D) variables.** In particular, the process of translating replaces each demand function in the class of demand functions $x_i = w^i(P,M)$ by the modified (translated) system:

$$x_i = \hat{w}^i(P,M) = d_i + w^i(p_i, M - \Sigma p_k d_k)$$

where $\hat{w}^i(\cdot)$ is a demand function, P is a vector of prices; p_k represents a specific price; the x_i's are quantities demanded; and M is expenditure. The d_i's are functions which describe the relationship between x_i and the E/D variables. For example, d_i might be written as:

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* See footnote 7 of Pollak and Wales (43) for a caveat on the plausibility of "translated" systems.

** As a reminder, recall that the demand systems are the solutions to the utility maximization problems described by Equations (4.7) and (4.8).

$$d_i = \alpha_i + \sum_{t=1}^{T} \delta_{it} E_t \qquad (4.15)$$

where α_i and δ_i are parameters and E_t is the t^{th} E/D variable (e.g., ambient annual 24-hour concentrations of SO_2).

In terms of the utility function, the original utility function of the form $U = U(x_1, x_2, \ldots x_n)$ is replaced by a "translated" system

$$\hat{U} = \hat{U}(x_1-d_1, x_2-d_2, \ldots , x_n-d_n) \qquad (4.16)$$

Intuitively, the process of translating permits the introduction of parameters which may increase or decrease demand, such that the changes are independent of prices and expenditure.

Scaling--

When "scaling" is used to introduce E/D variables into demand systems, the (scaling) factor is multiplicative. This is in contrast to translating which relied on an additive (translating) factor. Thus, n scaling factors $(r_1, \ldots , r_n)$ are introduced into a class of demand functions $x_i = w^i(P,M)$ such that the modified system becomes

$$x_i = \hat{w}^i(P,M) = r_i w_i(p_1 r_1, p_2 r_2, \ldots p_n r_n, M) \quad .$$

In this case, each scale factor r_i can be expressed as a function of E/D variables. A convenient specification of this relationship might be

$$r_i = 1 + \sum_{t=1}^{T} \alpha_{it} E_t \qquad (4.17)$$

where again E_t is the t^{th} E/D variable.

The process of scaling is consistent with the notion that the effects of the E/D variables are principally price dependent. This is in contrast to the translating process where the E/D parameters are introduced as additive effects which are independent of prices and expenditures.

In the present analysis, translating would seem to be the more appropriate concept. The hypothesis would be that E/D variables act as shifters to the quantities demanded of the various goods. In effect, variations in demand are permitted to occur, conditional on the levels of the E/D variables. With the scaling process, the price dependent nature of the transformation makes it difficult to isolate the effect of changes in the E/D variables (specifically air quality) on the aggregate index of service flows.

Translating and scaling also have implications for the scope of benefits associated with air quality changes. The introduction of air quality parameters as "shifters" to an original system of demand equations implies that air quality effects are viewed as affecting the utility function indirectly through a kind of production process of service flows. It is possible of course that some effects associated with air quality changes may be primarily utility effects. An example would be the amenities attached to simply having a cleaner environment. While the model presented in this section does not identify pure utility effects, it does have the advantage that welfare changes induced by alternative levels of air quality involve simple price changes rather than shifts in the utility function.*

Deviations From Assumptions of the Standard Utility Maximization Model

Two of the maintained assumptions in the standard utility model are that prices and income are fixed. These assumptions are examined more closely in this subsection.

The assumption of fixed prices can be interpreted as follows. The price for a good is determined through aggregate demand and supply forces in the market for the good. From the perspective of a single consumer, he is such an insignificant part of the total number of purchasers that any action he takes will have no affect on the market price he faces. Another way of stating this is that consumers behave as if they can buy all they desire of a specific good at the market-determined price.

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* In the Watson and Jaksch (15) article cited earlier, assumptions are adopted on the demand side that are consistent with observing no change in expenditures for a given change in air quality. Thus, the benefits of improved cleanliness identified in their model can be attributed to a pure utility effect.

Does the assumption that price is fixed and beyond the control of the consumer make sense for the model developed here? For the most part, the answer is yes. However, for those prices that may be affected by the location-specific attribute of air pollution, special assumptions may be required. As an example, people can change the rent schedule they face by moving to a location with different air quality attributes. Similarly, wage rates may be dependent on locational amenities. In this study, all location decisions are assumed to have been made, and any adjustments observed in the patterns of demand occur conditional on this decision. Thus, two plausibly significant means of adjustment are removed from the analysis.

These adjustment possibilities could be incorporated into the expenditure model if the model were tailored to reflect dynamic adjustments. That is, the location adjustment decision is viewed as occurring only in the long-run. The model developed in this section is a short-run, static model where long-run decisions are assumed fixed.*

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* A possible way to structure a long-run model would be to employ the notion of a conditional demand function. See Pollak (46).

Tests of Hypotheses

The purpose in constructing the elaborate two-stage model is to be able to estimate the benefits of air quality improvements. However, if the benefit numbers are to have meaning, they must be calculated from demand equations that are plausible and for which air pollution is a statistically significant explanatory variable.

The literature on physical damage functions reports a variety of products or activities that may be impacted by specific types of air pollution and this information can provide an *a priori* basis for including measures of air pollution in selected demand equations. Given an estimated coefficient for the air pollution variable, statistical tests must be undertaken to determine if the coefficient is statistically different from zero. That is, does air pollution have an effect on demand. Furthermore, one can check if the sign of the coefficient corresponds to *a priori* notions. In single equation, linear regression models, the Student t-test is used most frequently to identify statistical significance. In the present effort, nonlinearities within or across equations in the demand systems require the use of more sophisticated tests such as likelihood ratios. This test is explained more fully in the EMPIRICAL RESULTS subsection.

Summary of the Technical Model

In this subsection, a model based on individual behavior has been developed which can be used to identify the benefits associated with changes in air quality. The principle advantages of the model are that it is based on established economic theory and explicitly recognizes the decision-making ability of individuals. In addition, the estimation of demand systems permits the identification of benefits in a theoretically sound manner.

Implementation of the model described above requires the following steps:

- Define subfunctions of homogeneous groups of disaggregate goods.
- Estimate demand functions for the goods appearing in the subfunctions; air quality variables enter the model directly at this stage.
- Utilize the parameter estimates from the disaggregate demand functions to define aggregate price and quantity indices.
- Estimate the demand functions for the aggregate service flows.

With the aggregate price indices dependent on air quality, changes in air quality affect the demand for the aggregate service flows, and economic benefits can be estimated.

DESCRIPTION OF DATA

An empirical analysis of the model requires, at a minimum, expenditure data and either price or quantity information for a variety of budget items. Furthermore, the budget information must be available on a location-specific basis so that the appropriate air quality data can be merged. The objective of this subsection is to provide a detailed account of the economic data used in the empirical analysis. A description of the air quality data is available in Section 3.

Scope of Economic Data

In 1972-73 the Bureau of Census conducted a Consumer Expenditure Survey for the Bureau of Labor Statistics (BLS). Approximately 10,000 households from across the country were surveyed in each year, with expenditure data available for over 2,000 items.

This data set can be accessed via computer tapes created by BLS. Two tapes in particular -- the Interview Survey Detailed Public Use Tape No. 2 and the Diary Survey Public Use Tape -- provide the expenditure data required for this study. Unfortunately, confidentiality restrictions prevent the assignment of location identifiers to individual household records. Since it is imperative that location-specific air quality data be matched with location-specific expenditure information, the tapes cannot be used as the primary data source for the analysis.

BLS does, however, publish summary tables of information from the tapes. These tables report _average_ household expenditures by Standard Metropolitan Statistical Area (SMSA), and are available in BLS Bulletin 1992, _Consumer Expenditure Survey: Integrated Diary and Interview Survey Data, 1972-73_ (47). In this publication, the data include average household expenditures by SMSA for approximately 100 items. Unfortunately, for each item, the publication combines information from the two survey years into a single number.

This latter difficulty was resolved through contact with BLS personnel. In particular, an unpublished version of Bulletin 1992 data was obtained which distinguished between the survey years.* However, it was not possible to further augment the data either in terms of expenditure categories or the number of SMSAs reported.

Table 4-5 lists the SMSAs included in Bulletin 1992. Of the 28 cities listed, four had to be dropped because of data deficiencies elsewhere. Thus, the data set consisted of observations for 24 SMSAs in two different years.

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* George Weeden and Chuck Bailey of BLS were most helpful in providing this information.

TABLE 4-5. STANDARD METROPOLITAN STATISTICAL AREAS IN BULLETIN 1992

New York City
Boston
Philadelphia
Scranton*
Buffalo

Kansas City
Milwaukee
Minneapolis-St. Paul
St. Louis
Chicago
Cleveland
Cincinnati
Detroit

Atlanta
Baltimore
Washington, DC
Houston
Miami*

San Diego
Los Angeles-Long Beach
San Francisco-Oakland
Denver
Honolulu
Portland*
Seattle-Everett
Anchorage*

The expenditure categories included in Bulletin 1992 are listed in Table 4-6. In addition to these items, demographic and income information is also available. Of course, expenditure information alone is not sufficient for estimation of the two-stage budgeting problem. Price or quantity information is also required. Ideally, this data would have the same regional breakdown as that of the expenditure data.**

Such data does exist for prices. In 1971, BLS conducted a survey of average prices in 56 urban areas for approximately 200 detailed nonfood commodity and service categories. [U.S. BLS: "Average Retail

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* Not included in analysis due to data deficiencies elsewhere.

** See Pollak and Wales (41) for a discussion of the estimation of household budget data with no regional price variation and only two years of data.

TABLE 4-6. EXPENDITURE CATEGORIES IN BLS BULLETIN 1992

- Current consumption expenses, total
  - Food, total
    - Food at home, total
      - Cereals and cereal products
      - Bakery products
      - Beef
      - Pork
      - Other meats
      - Poultry
      - Fish and seafood
      - Eggs
      - Fresh milk and cream
      - Other dairy products
      - Fresh fruits
      - Fresh vegetables
      - Processed fruits
      - Processed vegetables
      - Sugar and other sweets
      - Nonalcoholic beverages
      - Fats and oils
      - Miscellaneous prepared foods, condiments, and seasonings
    - Food away from home
    - Meals as pay
  - Alcoholic beverages
  - Tobacco products and smoking supplies
  - Housing, total
    - Shelter, total
      - Rented dwellings
      - Owned dwellings
      - Other lodging, excluding vacation
    - Fuel and utilities, total
      - Gas, total
        - Gas, delivered in mains
        - Gas, bottled or tank
      - Electricity
      - Gas and electricity, combined bills
      - Fuel oil and kerosene
      - Other fuels, coal, and wood
      - Water, garbage, sewerage, trash, and other

(continued)

TABLE 4-6 (continued)

- Housing (continued)
  - Household operations, total
    - Telephone
    - Housekeeping and laundry supplies, total
      - Laundry and cleaning supplies
      - Other household products
      - Postage and stationery
    - Domestic and other household services
  - Housefurnishings and equipment, total
    - Household textiles
    - Furniture
    - Floor coverings
    - Major appliances
    - Small appliances
    - Housewares
    - Miscellaneous

- Clothing, total
  - Male's, 2 and over
  - Female's, 2 and over
  - Children's, under 2 years
  - Materials, repairs, alterations and services

- Dry cleaning and laundry

- Transportation
  - Vehicle purchases (net outlay)
  - Vehicle finance charges
  - Vehicle operations, total
    - Gasoline and fuels
    - Other
  - Other transportation

- Health care, total
  - Health insurance
  - Expenses not covered by insurance
  - Nonprescription drugs and medical supplies

- Personal care

- Recreation, total
  - Owned vacation home
  - Vacation and pleasure trips, total
    - Food
    - Alcoholic beverages

(continued)

TABLE 4-6 (continued)

- Recreational (continued)
    - Lodging
    - Transportation, total
        - Gasoline
        - Other transportation
    - All expense tours
    - Other vacation expenses
  - Boats, aircraft, and wheel goods
  - Other recreation, total
    - Television
    - Other
        - Pets, toys, and games
        - All other recreation expenses
  - Reading
  - Education, total
    - Private
    - Public
    - Day and summer camp
  - Miscellaneous

- Personal insurance, retirement, and pensions, total
  - Life, endowment, annuities, and income insurance
  - Other personal insurance
  - Retirement and pensions

- Gifts and contributions

Prices of Selected Commodities and Services, Fall 1971" (48)]. In this survey, prices were collected from a sample of outlets in each urban area, with particular attention given to identifying different levels of product quality for pricing purposes. Although the sample size for each item for each city is small (usually less than 20 observations), these are the best data available for place-to-place comparisons.

A question might arise as to the possibility of using a city- and category-specific Consumer Price Index (CPI) as a measure of price. The CPI measures the value of a particular bundle of goods as it changes over time. If, for example, a group of goods cost $10.00 in 1967 and $18.00 in 1980 (for the same goods), an index of 1.8 would describe the fact that prices had risen 80 percent relative to a base value in 1967. Typically, the base of the CPI is reported in terms of 100, so that in the above example, the CPI in 1980 would be 180.

While city-specific CPI exist, they are reported with each city indexed to 100 in the same year. Thus, the CPI only reveal changes across time within the city and cannot be used for place-to-place comparisons. There is no guarantee that the bundle of goods consumed in the base year represented equivalent levels of economic welfare across cities. Naturally, once place-to-place prices have been developed, the CPI is invaluable for adjusting prices across time.

Such an adjustment process was necessary for the nonfood price data described above. This occurs because the actual prices are in 1971 dollars, while the available expenditure information is drawn from 1972 and 1973.* Consumer price indices obtained from U.S. BLS: "Handbook of Labor Statistics, 1978" (49), Table 124, were used to bring prices and expenditures into comparable terms. Table 124 of

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* In the small number of cases where price data were missing for a particular item in a particular city, the average price for that item from cities with data was computed and assigned to the missing data cell.

Reference (50) contains CPI data for 23 of the SMSAs listed in Table 4-5 and six categories of consumer expenditure (All Items, Food, Housing, Apparel and Upkeep, Transportation, and Health and Recreation).*

As an example of the calculations required for price adjustment across time, consider the following. Assume that it is reported that the average price of a man's suit in Atlanta in 1971 is $200.00. Furthermore, assume that the "apparel and upkeep" CPI in Atlanta was 116.0 in 1971 and 118.7 in 1972. The price of a man's suit in Atlanta in 1972 can then be determined from:

$$200.00\left(\frac{118.7}{116.0}\right) = \$204.66$$

Given that the 1973 apparel CPI is also known, the price of a man's suit in 1973 can be determined in the same fashion. This adjustment procedure would take place for each good for which actual price data existed.

The price data available in Reference (49) do not include prices for food items. Such information is required in order to complete the match-up with the available expenditure information. Food prices were obtained from U.S. BLS: "Estimated Retail Food Prices by Cities, 1973 Annual Averages" (50). This publication contains detailed price information for nearly 100 food items for 23 of the SMSAs listed in Table 4-5.* Again, in order to make the 1973 (food) prices comparable to the 1972 and 1973 expenditure data, the "food" CPI was used to deflate the 1973 food prices to 1972 terms.

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* No detailed CPI information is published for Denver. Denver prices were adjusted with an average of the North-Central and West Regional CPI.

In summary, the economic data consist of expenditure data for 24 SMSAs for each of two years, and actual price information adjusted by a city- and category-specific CPI. The reader may have noted, however, that the level of detail available in the price data is greater than that available in the expenditure data. For example, expenditure information is available for "beef", while price information includes three different types of steak, three different types of roasts, and hamburger. Thus, adjustments are required to reconcile the levels of aggregation before estimation is possible.

Aggregation

In the subsection describing the technical model, the issue of aggregation was discussed briefly. The concern there was with necessary and sufficient conditions for the existence of a consistent aggregate price index. The framework within which the aggregation took place was the two-stage budgeting process, where the

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* Unpublished data on food prices for Denver were obtained from BLS.

(disaggregate) second stage was defined in terms of observed prices and expenditures.

The issue here is, can the available price and expenditure information be defined so that the disaggregate stage can be estimated? One of two alternatives is required. Either a way is found to disaggregate expenditures to the level of the demand prices or the observed prices must be aggregated to the level of expenditures. If the former option were possible and carried out, the econometric burden at the second stage would be severe, since actual price data exist for over 300 items. On the other hand, aggregation of the price data would leave a second stage estimation problem that would involve 50 or fewer goods. The problem with the latter approach is that the only method described thus far for consistent price aggregation involves estimation of systems of equations. Consequently, it would appear that a burdensome econometric problem still exists.

A Non-Econometric Approach to Consistent Indices--

Diewert (51) shows that it is possible to define consistent price and quantity indices without having to estimate a series of functions like those defined in the second stage of the budgeting procedure.

Diewert's approach is based on assuming a particular form for the "disaggregate" stage subfunction. The underlying preferences are assumed to come from a homogeneous translog specification. That is, if X is a vector of disaggregate goods, then the subfunction can be written as

$$\ln f(X) = \alpha_0 + \sum_{i=1}^{N} \alpha_i \ln x_i + \frac{1}{2} \sum_{j=1}^{N} \sum_{k=1}^{N} \beta_{jk} \ln x_j \ln x_k \qquad (4.18)$$

where $\Sigma_i \alpha_i = 1$ $\beta_{jk} = \beta_{kj}$ and $\Sigma_k \beta_{jk} = 0$ for $j = 1, \dots, N$. This function can be viewed as providing a second-order approximation to an arbitrary twice continuously differentiable linear homogeneous function [Diewert (51), p. 119].*

If this function is assumed to represent preferences at some disaggregate level, then a consistent quantity index, the Törnquist approximation to a Divisia index, can be defined. The index is written as:

$$Q(p^0, p^r, x^0, x^r) \equiv f(x^r)/f(x^0) = \prod_{n=1}^{N} \left(x_n^r / x_n^0\right)^{1/2\left(S_n^r + S_n^0\right)} \qquad (4.19)$$

where $f(\cdot)$ is the subfunction over which the aggregate commodity index is defined.

x^r refers to the vector of disaggregate goods in the r^{th} city.

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* Recall the conditions of the theorem concerning the existence of an aggregate price index. One of these conditions was that the subfunction be linearly homogeneous (i.e., of degree one).

x^0 is a normalizing factor for the vector of disaggregate goods. In a time series study, this would be a particular year. For our cross-section study, we have normalized on the basis of the average across all cities in our sample.

n indexes the number of goods in the disaggregate group. As written, the index defines an aggregate quantity measure for N disaggregate goods.

S_n^r is the expenditure share of the n^{th} disaggregate good in the r^{th} city. It is defined as $S_n^r \equiv p_n^r x_n^r / p^r \cdot x^r$.

S_n^0 is the expenditure share of the n^{th} disaggregate good for the "average" SMSA.

Equation (4.19) depends only on disaggregate price and quantity information. Although the assumptions required to form this index are comparable to those outlined for the two-stage method, in the present case there is no need to estimate econometrically a series of commodity subfunctions in order to define a consistent index. Note also that, given a consistent quantity index, a consistent price index can be defined from the following relationship:

$$P(p^0,p^r,x^0,x^r)Q(p^0,p^r;x^0,x^r) = p^r \cdot x^r/p^0 \cdot x^0 \qquad (4.20)$$

where P is the aggregate price index and Q is the aggregate quantity index defined above; $p^r \cdot x^r$ is the inner product of prices and quantities in the r^{th} city; and $p^0 \cdot x^0$ is the inner product of prices and quantities in the base city (i.e., average across SMSAs in the sample).*

The assumptions underlying construction of the Törnquist-Divisia (T-D) Index permit consistent price and quantity indices to be developed based only on price and expenditure information. However, the form of the index does not allow one to identify air quality effects. Consequently, the econometric procedure for deriving aggregate indices must still be used in the second stage of the budgeting procedure. The T-D index is useful for aggregating market prices to a level consistent with the "market" goods of this second stage.

Figure 4-6 outlines the process used to construct the various data files used in the analysis. The initial data requirement is price and expenditure information for very specific market goods. These data are obtained from the BLS tapes and Reference (48). Given this information, the T-D index is then used to aggregate the price and expenditure data to a level of 20 goods. This process is described in detail below.

The 20 goods defined in the T-D aggregation procedure represent the "market goods" that enter the subfunctions defined for the second

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* This relationship is known as the Fisher weak factor reversal test. It requires that a normalized price index times a normalized quantity index be equal to normalized total expenditures for all goods in the disaggregate group. See Diewert (51).

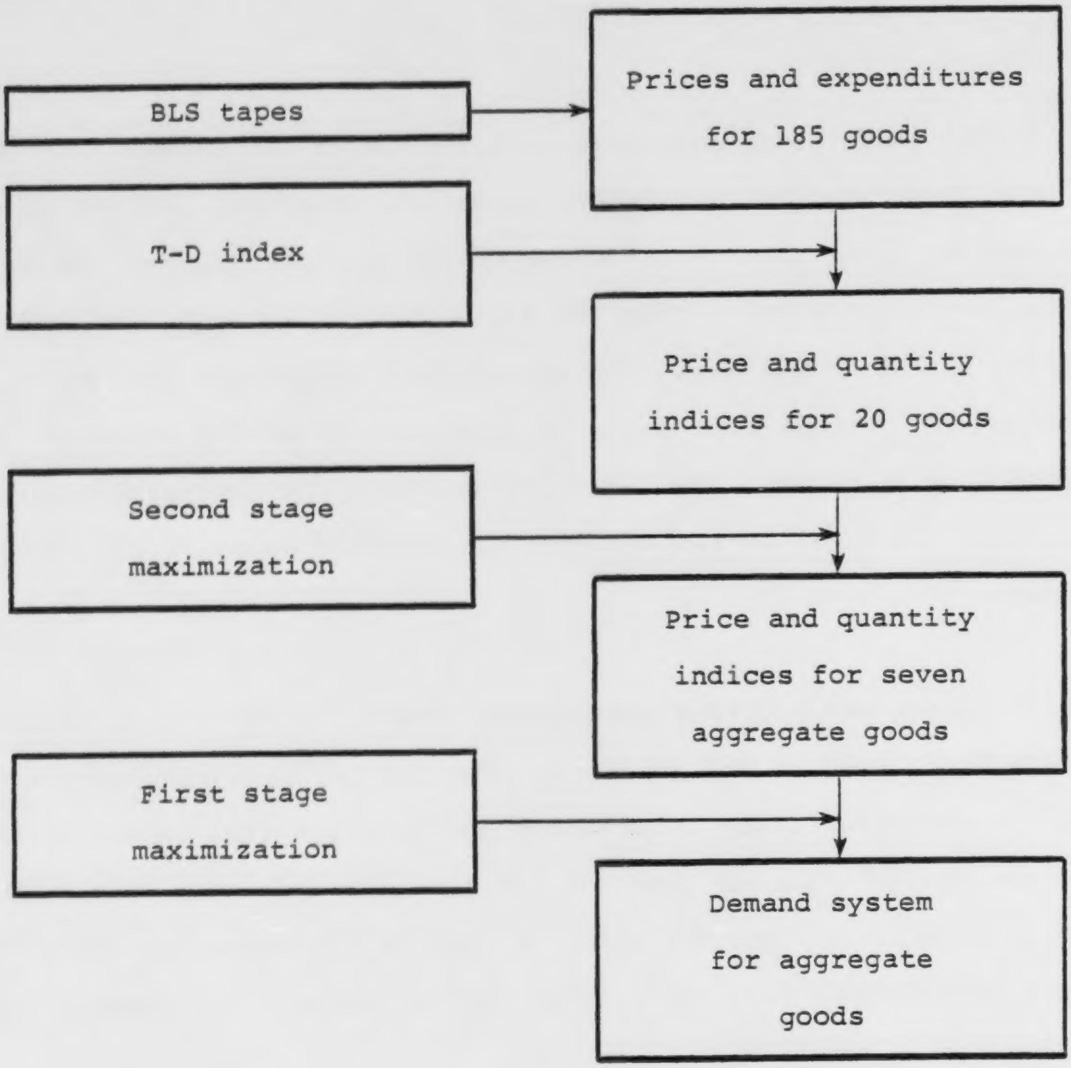
BLS tapes
Prices and expenditures for 185 goods
T-D index
Price and quantity indices for 20 goods
Second stage maximization
Price and quantity indices for seven aggregate goods
First stage maximization
Demand system for aggregate goods

Figure 4-6. Schematic of data development.

stage of the two-stage budgeting procedure. Thus, once the T-D aggregation has been performed, the procedures described in the Model Development subsection can be initiated. These steps are shown in the bottom part of Figure 4-6.

Definition of SMSA Expenditure Data--

As Equation (4.19) shows, disaggregate price and quantity information is needed to implement the (T-D) procedure. The price data are available (with SMSA variation) but quantity or expenditure data are not available at the same level of disaggregation on an SMSA by SMSA basis. In this case, however, it is possible to utilize the detailed BLS computer tapes from which the expenditure data were developed. Earlier, it was noted that the computer tapes could not be used in the estimation phase because specific location identifiers were not available. This was crucial when merging air quality data was an immediate concern. However, specific location identifiers are less crucial in forming measures of average expenditure for use in the (T-D) index. The type of location information that is available on the tapes is a regional identifier (Northeast, South, North Central, and West), and a code representing the city size of the respondent. This information can be used in conjunction with city-specific demographic characteristics to obtain a reasonable approximation to expenditure allocations on a city-by-city basis.

The following approach was used. First, 185 distinct goods were identified for which actual price data were available. Then the tape codes corresponding to these 185 items were entered in a computer program so that expenditure data for these items could be read from the tapes. In addition to the expenditure information, the computer program classified each household record by several characteristics: region of country (four possibilities); city size greater than 1,000,000 (one possibility);* race of family head (two possibilities -- black or non-black); education of family head (two possibilities -- greater or less than high school diploma). Thus, average expenditures for the 185 items were recorded for 16 different cells (4 regions x 2 race classes x 2 education classes). A typical entry might be interpreted as: The average non-white household in the West with the head of family having at least a high-school diploma spent $70 per year on bread.

Given this stratified information, the 1970 Census of Population (52) was used to obtain information on the percentage breakdown by SMSA of racial and educational attainment characteristics.** These percentages were then used as weights in order to identify SMSA-specific average expenditures for each of the 185 items.

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* The program was restricted to read only those records from households in areas of more than 1,000,000 people because our 24 SMSAs fall into this category (with the exception of Honolulu).

** This breakdown includes the cross-comparisons as well (e.g., the percent blacks with greater than a high school diploma).

To clarify this weighting process, consider the following example. Table 4-7(a) records hypothetical expenditure levels for good number XX in region 1. It is assumed that city A is in region 1 and has population characteristics as shown in Table 4-7(b).

With these data, the average expenditures in city A on good XX can be calculated as:

$10 x 0.01725 [$10 x % of total population that is black, ≥ 12 yrs. = (0.115 x 0.150)]
+ $12 x 0.26435 (0.26435 = 0.311 x 0.85)
+ $ 6 x 0.13275 (0.13275 = 0.885 x 0.15)
+ $ 5 x 0.58565 (0.58565 = 0.689 x 0.85)

= $7.069 = average expenditures in city A for good XX

This procedure is repeated for each SMSA for each of the 185 items for each of the two years. This procedure yields the disaggregate expenditure data needed to use the (T-D) index.

Application of the Törnquist-Divisia Index--

Given price and expenditure data for 185 items, the (T-D) index was employed to aggregate the price data to a level of 20 goods. This aggregation occurred in several stages. First, a price index for the 185 items was defined for 40 aggregate goods. These 40 goods corresponded to a level of detail consistent with the expenditure information available in Bulletin 1992. Next, the 40 item group was

TABLE 4-7(a). HYPOTHETICAL EXPENDITURES ON GOOD XX IN REGION 1

(Black, > 12 yrs.)	(Non-Black, > 12 yrs.)	(Black, < 12 yrs.)	(Non-Black, < 12 yrs.)
\$10.00	\$12.00	\$6.00	\$5.00

TABLE 4-7(b). HYPOTHETICAL DEMOGRAPHIC PERCENTAGES FOR CITY A IN REGION 1

(Black, > 12 yrs.)	(Non-Black, > 12 yrs.)	(Black, < 12 yrs.)	(Non-Black, < 12 yrs.)
11.5%	31.1%	88.5%	68.9%

Percent Black = 15%

aggregated to 20 goods. For this stage of aggregation, the expenditure data found in Bulletin 1992 was used to construct the expenditure shares needed for the (T-D) index.*

The price and expenditure data for these 20 goods formed the data set used in the second stage of the budgeting model. Table 4-8 lists the 20 items that make up the set of goods. Note that they are grouped into seven categories. This higher level of aggregation corresponds to data used in the first stage of the budgeting model. The conditions outlined earlier for the two-stage process to be valid require that the seven most aggregate goods be weakly separable in their subsets of goods. Thus, the manner in which the 20 goods are grouped places restrictions on the possible substitutions, where these groups reflect prior beliefs about how households make decisions. The groupings shown in Table 4-8 are consistent with the major classes of data items listed in Bulletin 1992.**

A statistical profile of the expenditure data is shown in Table 4-9 by category of goods. On average, these items account for 40

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* Explicit expenditure information was not available for one of the 40 items. This was home repairs. In Bulletin 1992, home repairs was lumped into the expenditures by renters or owners of property. Because of the possible importance of these expenditures in measuring air quality benefits, data on home repairs were read from the BLS computer tapes and assignment of an SMSA-specific home repair expenditure was calculated on the basis of percentages of home owners/renters in the SMSA.

** See Christensen and Manser (53) for an example of the procedures required to test separability assumptions. Their application focuses on the "meat" branch of the utility function.

TABLE 4-8. GOODS USED IN SECOND STAGE OF OPTIMIZATION MODEL

GROUP 1: FOOD

a. Cereal and Bakery Products
b. Meat
c. Dairy Products
d. Fruits and Vegetables
e. Miscellaneous Foods

GROUP 2: SHELTER

a. Home Repair
b. Utilities

GROUP 3: HOME OPERATIONS

a. Laundry and Cleaning Products
b. Other Household Products

GROUP 4: HOME FURNISHINGS AND EQUIPMENT

a. Textiles
b. Furniture
c. Major and Minor Appliances
d. Housewares

GROUP 5: CLOTHING

a. Men's, Women's, and Children's Clothes
b. Dry Cleaning

GROUP 6: TRANSPORTATION

a. Gas and Fuel
b. Other Vehicle Operations

GROUP 7: HEALTH AND PERSONAL CARE

a. Personal Care
b. Non-Prescription Drugs
c. Non-Insured Medical Treatment

TABLE 4-9. STATISTICAL PROFILE OF EXPENDITURE DATA -- ANNUAL HOUSEHOLD EXPENDITURE BY GOOD

Variable name	Mean	Std. deviation	Min	Max
Cereal/bakery products	136.33	22.62	69.04	177.23
Meats	428.10	89.53	283.71	657.62
Dairy products	184.20	25.47	126.63	230.25
Fruits and vegetables	172.73	29.14	115.70	249.92
Miscellaneous foods	523.37	58.63	322.19	675.53
Repair	129.26	26.70	76.33	179.02
Utilities	387.17	66.04	229.40	500.64
Laundry/cleaning	47.59	8.02	29.70	67.17
Other household products	47.28	9.16	26.68	68.19
Textiles	54.65	12.06	28.06	79.30
Furniture	145.80	37.38	82.78	268.54
Appliances	85.29	21.69	48.48	154.61
Housewares	20.46	6.24	9.55	39.05
Clothing	477.60	77.81	397.59	756.83
Dry cleaning	89.82	24.70	50.64	158.93
Vehicle gas and fuel	336.45	47.10	204.65	451.88
Other vehicle expenditures	427.47	50.93	327.06	529.43
Non-insured medical	273.50	43.15	171.09	353.63
Non-prescription drugs	54.59	21.50	14.93	92.63
Personal care	173.63	24.19	107.94	234.49

percent of current consumption expenditures. Statistics for the price data are given in Table 4-10. The means for the price indices are unity since all prices are normalized.

Limitations of Data--

The expenditure information drawn from Bulletin 1992 has several drawbacks. Foremost is the fact that only SMSA averages are reported. The utility maximization model defined here is based on the actions of individual consumers (or households acting as a single unit), so that estimation over SMSA averages presents a new kind of aggregation problem. Whether or not aggregation across individuals in the data creates real difficulty depends to some extent on the form of the utility function and the associated demand system. For example, Pollak and Wales (41) note that if the demand system is of the Linear Expenditure type, then no problem arises since the average consumption pattern of a group is consistent with the consumption pattern that would be observed given the group's mean expenditure.* Basically, the assumption made in this study is consistent with the notion that there exists a composite, representative individual.

The expenditure data could also be improved in terms of the geographic regions covered and the items defined. Both of these

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* Note that aggregation over individuals in the data is fundamentally different than aggregation across individual utility functions. In order to be able to aggregate across individual utilities, one must assume at the least that the marginal propensity to demand out of income be equal for all consumers. See, e.g., Mäler (21), p. 118, and papers by Lau (54) and Jorgenson, Lau and Stoker (55).

TABLE 4-10. STATISTICAL PROFILE OF PRICE DATA

Variable name (price of)	Min	Max	Std. deviation
Cereal/bakery products	0.645	1.638	0.196
Meats	0.673	1.504	0.168
Dairy products	0.636	1.564	0.177
Fruits and vegetables	0.639	1.736	0.196
Miscellaneous foods	0.680	1.611	0.172
Repair	0.443	1.552	0.266
Utilities	0.637	1.696	0.237
Laundry and cleaning	0.737	1.532	0.182
Other household products	0.655	1.457	0.163
Textiles	0.706	1.370	0.142
Furniture	0.650	1.425	0.203
Appliances	0.796	1.555	0.153
Housewares	0.520	1.450	0.208
Clothing	0.569	1.175	0.122
Dry cleaning	0.642	1.568	0.236
Vehicle gas and fuel	0.763	1.451	0.145
Other vehicle	0.735	1.402	0.137
Non-insured medical	0.631	1.350	0.174
Non-prescription drugs	0.638	1.734	0.284
Personal care	0.738	1.342	0.141

limitations could be overcome if it were possible to assign location identifiers to the BLS tape records. However, confidentiality restrictions, coupled with project time and resource constraints, limited further inquiry into these directions. Consequently, at least for the short-term, the scope of data found in Bulletin 1992 appears to be the best available.* One recommendation can be made, however. It is the intention of BLS to conduct continuing annual surveys of consumer expenditures. If some form of the economic model developed here is to be used for benefits analysis, it would be to the benefit of EPA to work with BLS in identifying areas of information needs. Thus, questionnaires developed for the expenditure surveys could be structured to obtain the type of data needed by economists to evaluate air quality welfare effects.

One other point should be mentioned with respect to the expenditure data. In Table 4-8, seven groups of category expenditure were listed. While these groups constitute a sizable proportion of consumption expenditures, they do not represent complete coverage. In particular, leisure-oriented activities (recreation, reading, etc.) have been excluded from the analysis. In essence, a separability assumption has been imposed. This was done for two reasons. First, many recreation activities take place at some distance from the home, and since the data do not identify where households recreate, there is no way to determine air quality parameters at the recreation site. Second, from a theoretical perspective, if leisure activities are considered a part of the complete demand system, one must be able to model the labor-leisure decision of consumers. Data limitations again precluded this particular extension of the model. While leisure decisions have been left out of the current analysis, this is certainly an area where extensions to the analysis should be considered in the future.

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* Some time was spent searching for expenditure data that were city-specific with an eye towards conducting a detailed intracity benefits analysis. No good data source was identified.

EMPIRICAL RESULTS

In this subsection, empirical results are presented for the two-stage optimization problem with air quality. Equations are presented for two alternative demand system specifications in order to get an idea of the sensitivity of the results to different structural forms.

The demand systems estimated are the linear logarithmic expenditure system which is derived from a homogeneous transcendental logarithmic (HTL) function [Lau, Lin and Yotopoulos (45)], and the linear expenditure system (LES) which was developed by Klein and Rubin (56) and is identified closely with the work of Stone (57).

Prior to a discussion of the results for these two systems, some general comments will be made on the overall approach to the empirical part of the study.

Framework for Empirical Analysis

For a given functional form, there are two stages in the estimation process. First, N disaggregate stage systems are estimated, where N is the number of broad categories identified in the aggregate stage of the budgeting problem. Given the parameters of the N disaggregate stage systems, the overall system is then estimated. As described earlier, the parameters of the disaggregate stage are important for defining consistent aggregate price indices. In total, there are N + 1 systems to estimate.

The estimation procedure used is the iterative Zellner technique (58).* This routine is appropriate for simultaneous estimation of all the equations in a disaggregate demand system because it allows cross-equation constraints implied by demand theory to be imposed directly. Note also that the iterative Zellner estimator is equivalent asymptotically to a Maximum Likelihood Estimator [Kmenta and Gilbert (59)].

In estimating a system of expenditure share equations, one equation must be dropped to prevent singularity of the covariance matrix. Singularity arises because the share equations sum to one, by definition. Fortunately, since iterative Zellner results in maximum likelihood estimates, the choice of the equation to be dropped can be made arbitrarily. Note also that if the system contains only two equations, then only one equation is estimated. In this case, a restricted version of Ordinary Least Squares (OLS) rather than the Zellner systems method is appropriate.

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* The Zellner routine in the GREMLIN set of programs of the TROLL software package was used for estimation.

In those instances where the Zellner routine was used, the estimation took place in two phases. First, each equation of the system was estimated by restricted OLS in order to derive a set of initial values for the parameters and begin the iterative Zellner estimation. It should be noted that the optimization algorithm only guarantees local optimums. Thus, while convergence to similar parameter estimates with different starting guesses cannot guarantee a global optimum, it does lend additional credence to the estimates. For the systems results reported here, alternative sets of starting guesses typically led to identical results out to the third decimal place.

The estimation of systems of equations in share form also has implications for the reported R^2. First, if households consume approximately constant shares given regional price variation, one can expect a low R^2. Second, the across-equation parameter constraints can result in negative R^2 being reported. Thus, although the R^2 is reported in later sections, for completeness, it is essentially meaningless in the context of Zellner estimation.

The way environmental/demographic (E/D) variables are handled in the estimation phase is also of concern. The discussion of translating and scaling indicated how the E/D variables might be included, but there has been no discussion thus far on the statistical implications of including alternative sets of E/D variables. In principle, the procedure of testing combination after combination of specifications until a "good" one is achieved has implications for the meaning of the statistical tests of significance. This can be especially important for the E/D variables since the *a priori* basis for including a particular variable may seem essentially arbitrary.

Two things can be done to limit the scope of equation testing. First, every effort should be made to identify meaningful *a priori* information. For example, previous consumer budget studies may have considered the impact of different demographic variables on demand [Pollak and Wales (41)]. Additionally, while our study is unique in its approach of embedding air quality information within a complete demand system framework, information from the Criteria Document (5) can provide guidance in this area.

The second thing that should be done is to develop a "game plan" for analyzing the statistical significance of E/D variables. Given the relatively small number of degrees of freedom, and the extended parameter requirements for systems of equations, a parsimonious selection process was adopted for the E/D variables.

The following procedure was employed. Initially, two demographic variables were considered for each equation -- family size and a dummy variable for region of the country.* The regional variable was equal to one for the Northeast and North Central SMSAs, and zero otherwise. There were also eight air quality and two meteorological variables to consider. These include:

- The maximum annual second high reading for SO_2 and TSP in the SMSA ($\mu g/m^3$).
- The maximum of annual arithmetic (geometric) means for SO_2 (TSP) in the SMSA ($\mu g/m^3$).
- The average of annual second highs for reporting sites in the SMSA for SO_2 and TSP ($\mu g/m^3$).
- The average of annual arithmetic (geometric) means from reporting sites in the SMSA for SO_2 (TSP) ($\mu g/m^3$).
- Annual average temperature for the SMSA in degrees Celsius.
- Annual total precipitation in millimeters.

While the Criteria Document suggests items that may be affected by SO_2 or TSP, information on the appropriate averaging times is more sparse. Consequently, preliminary testing of alternative pollution measures was conducted. These tests indicated that the maximum annual second high readings were the most robust variables in terms of magnitude, sign, and statistical significance. Thus, in the equation results presented here, only the maximum second high measures are included.

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* With two years in the sample, a dummy variable for Year may also seem to be a worthy demographic variable. We did want to limit the number of demographic variables, and in a choice between Region and Year, we felt the cross-sectional variations in Region would likely be more influential in explaining expenditure allocations.

Temperature and precipitation variables were also included in several of the disaggregate demand systems. Given the definition of the Region demographic variable, temperature and the region dummy may be expected to play similar roles. This was borne out in the testing of alternative specifications, and in some instances the greater locational specificity of temperature made it the preferred variable. The precipitation variable was never statistically significant in any of our test specifications, and has not been included in the results reported here.

The hypotheses to be tested take the form of restrictions on the E/D variables. Specifically, statistical tests are conducted to determine if the coefficients of the E/D variables are significantly different from zero. The test-statistic we employed for the systems estimates is based on the likelihood ratio λ, where

$$\lambda = \frac{\max L_A}{\max L_B} \tag{4.21}$$

The likelihood ratio is the ratio of the maximum value of the likelihood function L for the econometric model A (which imposes restrictions) to the maximum value of the likelihood function for the model B (which is unrestricted). In practice, a test-statistic is used which is based on minus twice the logarithm of the likelihood ratio. This test statistic is asymptotically chi-square with degrees of freedom equal to the number of restrictions to be tested.*

Finally, it should be noted that although the series of equations presented below are termed "final specifications", an important part of the analysis plan involves identifying the sensitivity of results to alternative specifications, especially with respect to the role of the air pollution variables. Thus, an indication of the stability of the equations for different specifications is provided throughout. Where possible, these tests of sensitivity are also carried forward to the derivation of aggregate price indices and ultimately to the benefits calculations.

Linear Expenditure System

The first functional form evaluated is the Linear Expenditure System (LES). This system was one of the earliest demand system forms to be subjected to extensive empirical testing, and has been used frequently over the last two decades.

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* In those systems where there are only two goods, so that only one equation is estimated, an F-test is used to test for statistical significance. Note that because different criteria are used in testing the various specifications, there is a possibility that conflicts on appropriate restrictions could arise in those cases where the decision to reject or fail to reject is close [Bernt and Savin (60)]. With respect to the statistical tests conducted for the environmental variables of the analysis, the decision was uniformly clearcut.

The LES demand equations can be written (in expenditure form) as:

$$p_i x_i = p_i s_i + b_i \left(M - \sum_{k=1}^{n} p_k s_k \right) \qquad i=1, \ldots, n \qquad (4.22)$$

where p_i is the price of the i^{th} good, x_i is quantity demanded of the i^{th} good, M is total expenditure for the n goods in the system, and s_i and b_i are parameters to be estimated. This system has 2n-1 independent parameters and is generated from a utility maximization problem in which utility is defined as:

$$U = (x_i - s_i)^{b_1} (x_2 - s_2)^{b_2} \ldots , (x_n - s_n)^{b_n} \qquad (4.23)$$

In most applications of the LES system, the s_i are interpreted as "necessary" quantities. Thus, the term $(M - \Sigma p_k s_k)$ in Equation (4.22) can be viewed as representing available expenditure net of committed expenditure. Note, however, that this interpretation is realistic only if the s_i are restricted to be positive. Since there is no theoretical reason for imposing this restriction, we have left the signs of the s_i as an empirical question. An implication of this is that both inelastic demands ($s_i > 0$) and elastic demands ($s_i < 0$) are permitted.

There are a variety of restrictions or assumptions that are implicit in the LES system. These include:

- Each x_i must be greater than the corresponding s_i if the utility function is to be well-defined.

- The marginal budget shares are independent of prices and expenditures.

- The utility function of the LES is additive in the logarithms. This restricts the types of interactions permitted among goods.

- The Engel curves are linear but pass through the point $(s_1, s_2, \ldots, s_n)$ rather than $(0, 0, \ldots, 0)$. Thus, it is possible to observe the share of a commodity in the budget increase or decrease as the budget increases.*

- The LES utility function is affinely homothetic. That is, the function is homothetic to the point $(s_1, s_2, \ldots, s_n)$.

- The conditions for consistent price and quantity aggregation can be satisfied since the LES system can be written as a "Gorman polar form." [See Blackorby, et al. (35), Section 5.4.4.]

For estimation purposes, it is convenient to rewrite Equation (4.22) in share form and to normalize by total expenditure. In particular, the estimating form can be written as:

$$\frac{p_i x_i}{M} = (1-b_i)s_i(p_i/M) + b_i - b_i\left(\sum_{\substack{k=1 \\ k\neq i}}^{n} s_k(p_k/M)\right) \qquad (4.24)$$

for i = 1, ... , n.

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* See Anderson (61) for a discussion of an additive perfect price aggregate model (APPAM), which is an additive specification with nonlinear Engel curves.

The empirical restrictions implicit in the system of equations represented by (4.24) include:

- With Equation (4.24) expressed in share form, only n-1 equations are estimated. The unestimated b_i can be obtained from the restriction $\Sigma b_i = 1$.
- Across-equation constraints exist for the s_i parameters. Thus, a system method is required in order to obtain efficient estimates of the parameters.
- The LES system is nonlinear in the parameters. For example, the first term includes the product $(1-b_i)s_i$ where b_i and s_i are both parameters.
- Environmental/demographic variables can be incorporated through the translating technique. For the LES system, this implies replacing each s_i by a functional expression in the E/D variables. In this study, we have examined variations of a linear functional expression. For example, we might write $s_i = \alpha_0 + \alpha_1 TSP$, where TSP is the level of particulate matter concentration and α_0, α_1 are parameters to be estimated.*

The various empirical and structural restrictions listed above become important in the evaluation of the strengths and weaknesses of a particular model. These features have only been summarized at this point because it is likely to be more instructive to discuss them in the context of specific equation results.

The first use of the LES is in the estimation of the disaggregate demand systems of the two-stage budgeting problem. The equation specifications for each of the seven disaggregate systems are as shown in Equation (4.24). Table 4-11 lists the commodities in each of the demand systems, and Table 4-12 is a glossary of the acronyms used in reporting the equations. Recall that because the dependent variables are shares and sum to unity, only n-1 equations for any system are estimated. The value of the unestimated b_i can be easily derived from the adding-up restriction.

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* Pollak and Wales (43) discuss the importance of retaining an intercept term (i.e., α_0) in the functional expression for the translating parameter.

Food--

The estimating form represented by Equation (4.24) can be thought of as a restricted form in the sense that the necessary quantities, the s_i, are introduced as a simple parameter. It was noted that one way in which E/D variables may be incorporated into the LES specification is by replacing each s_i by a function of the E/D variables. For example, one could let $s_i = d_i + e_i$ FAMSZ. In this case, Equation (4.24) would be written as:

$$\begin{aligned}\frac{p_i x_i}{M} = {} & (1 - b_i)(d_i + e_i \text{ FAMSZ})(p_i/M) \\ & + b_i - b_i\left(\sum_{\substack{k=1\\k\neq i}}^{n} (d_k + e_k \text{ FAMSZ})(p_k/M)\right)\end{aligned} \tag{4.25}$$

for i = 1, ... , n.

A comparison between Equations (4.24) and (4.25) makes clear why Equation (4.24) is referred to as being restricted. Estimation of

TABLE 4-11. COMMODITIES IN DEMAND SYSTEMS OF THE SECOND STAGE OF THE OPTIMIZATION MODEL

GROUP 1: FOOD

a. Cereal and Bakery Products
b. Meat
c. Dairy Products
d. Fruits and Vegetables
e. Miscellaneous Foods

GROUP 2: SHELTER

a. Home Repair
b. Utilities

GROUP 3: HOME OPERATIONS

a. Laundry and Cleaning Products
b. Other Household Products

GROUP 4: HOME FURNISHINGS AND EQUIPMENT

a. Textiles
b. Furniture
c. Major and Minor Appliances
d. Housewares

GROUP 5: CLOTHING

a. Men's, Women's, and Children's Clothes
b. Dry Cleaning

GROUP 6: TRANSPORTATION

a. Gas and Fuel
b. Other Vehicle Operations

GROUP 7: HEALTH AND PERSONAL CARE

a. Personal Care
b. Non-Prescription Drugs
c. Non-Insured Medical Treatment

TABLE 4-12. GLOSSARY OF VARIABLE NAMES

MFOOD	Total expenditure on all food items.
CERBAK	Expenditure on cereal and bakery products.
CEBAPI	Price of cereal and bakery products.
BEPOUK	Expenditure on meats (beef, poultry, pork).
BEPKPI	Price of meats.
DREGGS	Expenditure on dairy products and eggs.
DREGPI	Price of dairy products.
FRUVE	Expenditure on fruits and vegetables.
FRVEPI	Price of fruits and vegetables.
MISCFD	Expenditure on miscellaneous food items.
MISCPI	Price of miscellaneous food items.
MSHELTER	Total expenditure on home shelter.
REPAIR	Expenditure on home repair.
RPRPI	Price of home repair.
UTIL	Expenditure for gas and electricity.
UTILPI	Price of gas and electricity.
MOPS	Total expenditure on household operations.
LAUCLE	Expenditure on laundry and cleaning products.
LAUCPI	Price of laundry and cleaning products.
OHOUSE	Expenditure on other household products.
OHSEPI	Price of other household products.
MOUSE	Total expenditure on home furnishings and equipment.
HTEXT	Expenditure on household textiles.
HTEXPI	Price of textiles.
FURN	Expenditure on furniture.
FURNPI	Price of furniture.
APPLS	Expenditure on major and minor appliances.
APPPI	Price of appliances.
HWARS	Expenditure on housewares.
HWARPI	Price of housewares.
MCLOTH	Total expenditure on clothing items.
MCLO	Expenditure on clothes.
MCLOPI	Price of clothes.
DRYCL	Expenditure on dry cleaning.
DRYCPI	Price of dry cleaning.
MTRANS	Total expenditure on transportation.
VEHGF	Expenditure on gasoline.
VHGFPI	Price of gasoline.
VEHO	Expenditure for other vehicle operations.
VEHOPI	Price of other vehicle operations.

(continued)

TABLE 4-12 (continued)

MCARE	Total expenditure on health and personal care items.
PERSCR	Expenditure on personal care.
PERSPI	Price of personal care.
NONINS	Expenditure for non-insured medical care.
NINSPI	Price of non-insured medical care.
NONPRE	Expenditure for non-prescription drugs.
NPREPI	Price of non-prescription drugs.
Y11, Y12, Y13, Y14, Y15	Expenditure shares for cereal/bakery products, meats, dairy products, fruits and vegetables, and miscellaneous foods, respectively.
Y21, Y22	Expenditure shares for repair and utilities, respectively.
Y31, Y32	Expenditure shares for laundry/cleaning products and other household products, respectively.
Y41, Y42 Y43, Y44	Expenditure shares for textiles, furniture, appliances, and housewares, respectively.
Y51, Y52	Expenditure shares for clothing and dry cleaning, respectively.
Y61, Y62	Expenditure shares for vehicle gasoline and other vehicle operations, respectively.
Y71, Y72 Y73	Expenditure shares for non-insured medical care, non-prescription drugs, and personal care, respectively.
FAMSZ	Number of people in family.
REGION	Dummy variable for region of country (1 = Northeast or North Central; 0 otherwise).
TEMP	Average annual temperature in degrees Celsius.
SX2HI	Annual average of maximum second high concentrations of SO_2, for 24-hour continuous monitors.
TX2HI	Annual average of maximum second high concentrations of PM for 24-hour hi-vol grammetric monitors.

(4.24) implicitly assumes that the e_i and e_k terms are zero. The approach adopted in each demand category thus involves a generalization of the restrictive (4.24) so that E/D variables can be used to help explain some of the variation in the expenditure shares.

In the food category, there is no a priori reason to expect environmental variables to have an influence on the intracategory allocation of food expenditures. Thus, the initial specifications include only the demographic variables family size and region.

The unrestricted counterpart to Equation (4.24) is an equation system where each s_i is replaced by a function that depends on family size and region. It is convenient to specify this relationship as being linear in the demographic variables. Note that because there are "n" s_i terms appearing in each equation of the LES system, the linear expression will also appear n times. Thus, 2n parameters are added to the estimation process when the unrestricted form is estimated.*

In order to arrive at a final specification, the null hypothesis that a subset of the demographic variables is zero is tested. This is done with the test-statistic λ described earlier. Specifically, it is assumed that the error terms of the equations are distributed normally and write the likelihood ratio as:

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* Note that the system is unrestricted only in the sense that it has been assumed that the universe of relevant demographic variables can be limited to family size and region.

$$-2 \ln \lambda = N(\ln |S^{-1}|_u - \ln |S^{-1}|_r) \qquad (4.26)$$

where N is the number of observations, $|S^{-1}|_u$ is the determinant of the unrestricted estimator of the variance-covariance matrix of the disturbances, $|S^{-1}|_r$ is the determinant of the restricted estimator of the variance-covariance matrix of the disturbances, and ln is the natural logarithmic function.*

Table 4-13 reports the final specification for the food demand system. Note that in the equation specifications some of the demographic variables have been restricted to zero. The likelihood ratio test between the unrestricted model and the model shown in Table 4-13 yields a test-statistic of 2.699. With four restrictions, the chi-square critical value at the 10 percent level of significance is 7.78. Consequently, with the test-statistic less than the critical value, we fail to reject the null hypothesis that the restricted demographic variables are zero. That is, the restricted model is adopted.

Additional restrictions were imposed on the food demand system, but the results shown in Table 4-13 were eventually chosen as the

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* See Gallant (62) for a discussion of the use of the likelihood ratio test for hypothesis testing in nonlinear equations.

TABLE 4-13. LES FOOD DEMAND SYSTEM

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==============================================================================

1:     Y11 = (1-B1)*(C0+C1*FAMSZ+C2*REGION)*(CEBAPI/MFOOD)+B1-B1*((D0+D1*FAMSZ)*(BEFKPI/MFOOD)+(E0+E1*FAMSZ)
       *(DREGPI/MFOOD)+(F0+F1*REGION)*(FRVEPI/MFOOD)+(G0+G1*FAMSZ)*MISCPI/MFOOD)

2:     Y12 = (1-A1)*(D0+D1*FAMSZ)*(BEFKPI/MFOOD)+A1-A1*((C0+C1*FAMSZ+C2*REGION)*(CEBAPI/MFOOD)+(E0+E1*FAMSZ)
       *(DREGPI/MFOOD)+(F0+F1*REGION)*(FRVEPI/MFOOD)+(G0+G1*FAMSZ)*(MISCPI/MFOOD))

3:     Y13 = (1-H1)*(E0+E1*FAMSZ)*(DREGPI/MFOOD)+H1-H1*((C0+C1*FAMSZ+C2*REGION)*(CEBAPI/MFOOD)+(D0+D1*FAMSZ)
       *(BEFKPI/MFOOD)+(F0+F1*REGION)*(FRVEPI/MFOOD)+(G0+G1*FAMGZ)*(MISCPI/MFOOD))

4:     Y14 = (1-J1)*(F0+F1*REGION)*(FRVEPI/MFOOD)+J1-J1*((C0+C1*FAMSZ+C2*REGION)*(CEBAPI/MFOOD)+(D0+D1*FAMSZ
       )*(BEFKPI/MFOOD)+(E0+E1*FAMSZ)*(DREGPI/MFOOD)+(G0+G1*FAMSZ)*(MISCPI/MFOOD))

          CONVERGENCE OBTAINED

          CONVERGENCE ON S OBTAINED

          MODEL: FOOD   NOB = 48   NOVAR = 15   NOEQ = 4
          OPT ALGORITHM: DAVIDON-FLETCHER-POWELL
          OPT OPTIONS:  RADIUS = 1.         CONCR = 0.001      ITER LIMIT = 10
          INITIAL S MATRIX:  RESIDUALS CALCULATED FROM INITIAL COEFFICIENT ESTIMATES
          ITERATIVE 3SLS SELECTED:  ITER LIMIT = 25   CONCR = 1.000000E-05
          INITIAL H-INVERSE:  DEFAULT START

           COEF           VALUE          STD ERR          T-STAT

           B1           0.108797        0.007373        14.7571
           C1           5.83335         8.03527          0.725969
           D1          72.8674         27.0246           2.69634
           F1          -9.68198         5.69472         -1.70017
           E1         -33.7867         11.453           -2.95004
           C2           3.82399         4.76779          0.802048
           G0         166.928         132.36             1.26117
           G1         -69.7186         41.1664          -1.69358
           F0           3.57395        15.8434           0.22558
           A1           0.298796        0.019845        15.0565
           E0          62.2207         36.541            1.70276
           J1           0.108446        0.009759        11.112
           D0        -257.031          82.2993          -3.12313
           C0         -55.5988         26.3557          -2.10956
           H1           0.136394        0.008116        16.8059

          SINGLE EQUATION STATISTICS

          |============|================|================|================|================|
          |            |            RSQ |           CRSQ |            SSR |             DW |
          |============|================|================|================|================|
          | EQN 1      |       0.356847 |       0.160328 |       0.002509 |      1.84939   |
          | EQN 2      |       0.286574 |       0.068582 |       0.030957 |      2.37989   |
          | EQN 3      |       0.301286 |       0.08779  |       0.005429 |      2.44688   |
          | EQN 4      |       0.175827 |      -0.076003 |       0.0046   |      1.86055   |
          |============|================|================|================|================|

==============================================================================
```

final specification. As a point of interest, a comparison of the final specification with the completely restricted model led to a test-statistic greater than 45. Thus, the inclusion of the demographic variables does add to the explanatory power of the equation.

Table 4-14 reports own-price elasticities of demand for the demand system of Table 4-13.* The elasticities are evaluated at the means of the variables. The own-price elasticity measures the responsiveness of quantity demanded of a good to a change in its price. Demand is said to be elastic if a rise in price leads to a proportionately greater decline in quantity demanded so that total expenditure of the commodity declines. This is consistent with the elasticity measure being greater (in absolute value) than unity.

TABLE 4-14. OWN-PRICE ELASTICITIES OF DEMAND FOR FOOD DEMAND CATEGORY

Commodity	Elasticity
Cereal and baking products	-1.245
Meat products	-1.079
Dairy products	-1.159
Fruits and vegetables	-0.985
Miscellaneous foods	-1.041

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* Note that the nonlinearities in the LES system make it difficult to assess the statistical significance of the elasticity measures. Consequently, the standard errors of the elasticities for the LES system have not been computed, except in the two-equation systems, when we consider the pollution elasticities.

Conversely, demand is inelastic if a price increase leads to a smaller change in quantity demanded such that total expenditure increases. For the LES system, the own-price elasticities are obtained by evaluating the relationship:

$$\varepsilon_{ii} = \frac{\partial x}{\partial p_i} \frac{p_i}{x_i} = - \frac{b_i}{p_i x_i} \left[M - \sum_{\substack{k=1 \\ k \neq i}}^{n} p_k s_k \right] \qquad (4.27)$$

The demand elasticities for the food items are slightly elastic for four out of the five goods. We have not found elasticity estimates in the literature corresponding to the disaggregate breakdown reported here. However, many authors report elasticities for an aggregate food commodity. For example, Pollak and Wales (43) estimate a Quadratic Expenditure System (QES) and a Generalized Translog (GTL) for different combinations of family size and age composition for three aggregate goods. The reported elasticities for the food category range from -0.84 to -1.17 for "middle-level" combinations of the demographic characteristics, so that our estimates are representative of food elasticities reported by Pollak and Wales.

One can also examine the responsiveness of demand to changes in the demographic variables. However, since the major interest relates to the role of the environmental variables in the demand system, a discussion of this topic is postponed until the results for the next commodity group are reviewed. The next group, home services, includes both TSP and SO_2 in the specifications.

Shelter—

The disaggregate demand system for shelter is composed of two goods; materials repair and utilities (gas and electricity). Since the equations are expressed in share form, only one equation is estimated.

Hypothesis testing for the two-good systems in the analysis is based on an F-test rather than the likelihood ratio. In particular, we test whether specific subsets of additional explanatory variables are statistically different from zero. The appropriate test statistic is:

$$\left[\frac{R_u^2 - R_r^2}{1 - R_u^2}\right] \cdot \left[\frac{N - n_u}{n_u - n_r}\right] \sim F_{n_u - n_r,\, N - n_u} \qquad (4\text{-}28)$$

where R_u^2 is the R^2 of the unrestricted equation, R_r^2 is the R^2 of the restricted equation, N is the number of observations, n_u is the number of parameters estimated in the unrestricted equation, and n_r is the number of parameters in the restricted equation. If the evaluation of Equation (4.28) leads to a value greater than the critical F-value, then one rejects the null hypothesis that the (restricted) parameters are zero.

There were several stages in the analysis of alternative specifications for this commodity group. First, a series of regressions which included the two demographic variables in several combinations were analyzed. In comparisons between the completely restricted model and models with FAMSZ and Region, we failed to reject the null hypothesis in all cases except when Region was used as a shifter affecting repair. However, when the influence of pollution was controlled for in the specification, the Region variable did not add significantly to the explanatory power of the equation. Thus, in the equations of this demand system, neither of the demographic variables is included.

The environmental variables are statistically different from zero when entered in a variety of combinations. As used here, the term combination refers to the different specifications which can be generated by restricting certain of the environmental variables to zero. The unrestricted specification includes TSP and SO_2 measures in both of the translating terms. In addition to the unrestricted model, several other specifications were estimated with SO_2 and TSP. A summary of the equations estimated is presented in Table 4-15. In the table, the entries for the elasticities are presented on an equation-by-equation basis. For each equation, a description is given for the combinations of TSP and SO_2 included in the specification. For example, in equation 4, SO_2 is restricted to zero as a translating parameter for utility, while TSP is restricted to zero as a translating parameter for repair. Note that all entries are reported for the case in which the dependent variable is "repair".

TABLE 4-15. ELASTICITIES OF ENVIRONMENTAL VARIABLES IN THE SHELTER DEMAND SYSTEM (dependent variable repair)

Equation	Elasticity
Equation 1 (unrestricted)	
SO_2 included in both translating terms	0.069
TSP included in both translating terms	-0.066
Equation 2	
SO_2 included in repair translating term	0.063
TSP included in repair translating term	-0.078
Equation 3	
SO_2 included in repair translating term	0.049
TSP included in utility translating term	-0.072
Region dummy included in repair translating term	--
Equation 4	
SO_2 included in repair translating term	0.061
TSP included in utility translating term	-0.075

The elasticities for the environmental variables are defined as the percent change in demand that occurs for a percent change in air quality. The elasticities in Table 4-15 indicate that an increase in SO_2 concentrations leads to an increase in the demand for home repairs. Conversely, TSP is seen to have a negative relation with the demand for home repairs. Given that these estimates are derived for a two-equation system, this latter result can be interpreted as indicating a direct relation between TSP and the demand for utilities.

Given the inherently nonlinear form of the LES system (in terms of the parameters), the interpretation of statistical significance for the elasticities must be made carefully. First, it should be noted that t-statistics reported for individual coefficients do have meaning since the coefficients are asymptotically normally distributed. However, in order to talk about significance levels for elasticities or for variables that appear more than once in the equation, two intermediate steps must be undertaken.

First, it is convenient to linearize the equation directly. This is accomplished by replacing products of coefficients by a single parameter. The equation can then be estimated in linear form. Given the linearized regression, the statistical significance of the elasticity can be checked by the formula for calculating the variance of a linear combination of random variables. This can be written as:

$$\mathrm{Var}(\alpha_0 + \alpha_1 x_1 + \ldots , + \alpha_n x_n) = \sum_{i=1}^{n} \alpha_i^2 \,\mathrm{Var}(x_i) + \sum_{\substack{i=1 \\ i \neq j}}^{n} \sum_{j=1}^{n} \alpha_i \alpha_j \,\mathrm{COV}(x_i, x_j) \qquad (4.29)$$

where the α_i are constants and the x_i are random variables.

When these steps are undertaken for the various specifications shown in Table 4-15, each of the calculated air quality elasticities is significantly different from zero.

From the elasticities reported in Table 4-15, one can see that each specification is fairly stable with respect to combinations of the environmental variables. In order to choose among the different equations, elasticities were compared and, where appropriate, the F-test statistic was used. For example, in a comparison between the unrestricted model and Equation 4 of Table 4-15, the test-statistic was 0.415, which is less than the critical F-value. Thus, the restricted model is adopted in this comparison.

There is one other important point to mention about the manner in which the combinations of environmental variables are allowed to appear in the specifications. It turns out that not every combination is consistent with an aggregate price index that behaves in accord with *a priori* expectations. In particular, we note that the unrestricted model may be consistent with an aggregate price increase or decrease depending on the marginal budget shares of the goods involved in the aggregation. Consequently, this is an instance where it is helpful to use the prior information available about the types of goods or services that may be affected by air pollution.

Before choosing a final specification for this demand category, there was one more check performed for the environmental variables.

While alternative combinations of SO_2 and TSP have been considered, one can also examine different transformations of these variables. For example, the logarithms of both variables could be entered as explanatory variables or quadratic terms could be added. The choice could once again be based on elasticities.

These checks were undertaken, and it was decided to use the linear specification of the environmental variables. The final specification for this demand category is shown in Table 4-16.

The dependent variable in the equation of Table 4-16 is the share of shelter expenditure on home repair. Thus, the parameter estimate for SO_2 indicates that as concentrations of SO_2 decrease, relatively less will be spent on home repairs. In turn, the equation also shows that there is a direct relationship between TSP and the unestimated good, utilities. The demand elasticity for SO_2 is 0.0611 in the home repair equation. This means that a 10 percent decrease in SO_2 concentrations leads to a 0.611 percent decrease in the demand for home repair items. The elasticity for TSP is -0.075 in the home repairs equation. Elasticities can also be derived for the pollution variables implicit in the unestimated second equation. These elasticities are -0.020 and 0.025 for SO_2 and TSP, respectively.

The observed relation between SO_2 and home repairs is plausible. However, there was no a priori expectation that a positive relation would be observed between TSP and expenditures for utilities. As the

TABLE 4-16. LES SHELTER DEMAND SYSTEM

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  2:  Y21 = (1-A1)*(C0+C1*SX2HI)*(RPRPI/MSHELTER)+A1-A1*((D0+D1*TX2HI)*(UTILPI/MSHELTER))

  NOB = 48      NOVAR = 5
  RANGE =  1 TO 48
  RSQ =    0.26585      CRSQ =    0.19756     F(4/43) =      3.893
  SER =    0.0301       SSR = 3.908E-02       DW(0) =  2.48      COND(X) =     15.55
  LHS MEAN =       0.25069      SR =       0.00001

  COEF            VALUE          ST ER          T-STAT          MEAN

  A1             0.23301        0.01562        14.91350         1.26650
  C0           -32.23830       15.55350        -2.07274         0.00153
  C1             0.02393        0.00977         2.44894         0.63761
  D0          -149.34600       47.04200        -3.17474    -4.73298E-04
  D1             0.12010        0.05375         2.23440        -0.15767

  COEF           PARTIAL          BETA

  A1             0.91542        0.91254
  C0            -0.30139       -0.49978
  C1             0.34986        0.34902
  D0            -0.43576       -0.82629
  D1             0.32253        0.30094

                            COVARIANCE MATRIX

  A1            2.441E-04
  C0           -7.854E-02      2.419E+02
  C1           -4.420E-05     -6.206E-02      9.551E-05
  D0            2.417E-01      5.119E+02     -2.042E-01      2.213E+03
  D1            1.743E-04     -6.582E-02      3.820E-05     -6.367E-01      2.889E-03
==================================================================================
```

results shown in Table 4-16 indicate, a positive relation does exist. One explanation for this result is that TSP is picking up regional differences. That is, TSP is serving as a proxy for the added heating requirements (and hence higher utility bills) in colder areas. This was not substantiated in a specification with TSP and region or temperature variables. Another possible explanation is that electricity is used in conjunction with other goods to mitigate the effects of air pollution. For example, in areas where relatively more vacuuming, air filtering, etc. is required, the demand for electricity could be expected to be somewhat higher.

With respect to the economic characteristics of the equation system, the own-price elasticities are -1.126 and -1.067 for home repairs and utilities, respectively. We have seen no other budget studies that identify home repairs as a separate item. However, for utilities, our elasticity estimate is in the range of elasticities (-0.86 to -1.46) reported by Taylor (63) in a survey of residential electricity demand studies.

The discussions have been rather extended in both the food and shelter categories. This was done in order to lay out in some detail the testing procedures that were undertaken in the evaluation of alternative models. From this review of the different specifications of the air quality variables, we feel reassured that the variables are fairly stable. After a discussion of the remaining demand categories of the LES, the chosen specifications are subjected to one more sensitivity test. Specifically, a different structural model, the homogeneous translog, is adopted. Estimation of demand equations for this other system permits a comparison of price elasticities as well as the marginal effects of the air pollution variables with the results reported for the LES.

Home Operations--

Table 4-17 presents the final specification for the home operations demand system. There are two sets of aggregate goods included in this system -- laundry/cleaning products and "other household products". In the second group, items such as paper products, air fresheners, and insect sprays are included. Unfortunately, data limitations did not allow the formation of an aggregate variable of "household services" which includes expenditure items like lawn care, gardening services, and appliance repair services.

The home operations subsystem is a two-good system, so that OLS procedures are appropriate and testing is based on the F-test. As expected, TSP has a direct relation with the demand for laundry/cleaning products and is statistically significant. In alternative specifications with family size and SO_2, we could not reject the null hypothesis that the coefficients of these variables were zero. However, the Region dummy is statistically significant and an evaluation of the partial derivative of the quantity demanded of laundry/cleaning products with respect to region results in a direct

TABLE 4-17. LES HOME OPERATIONS DEMAND SYSTEM

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==========================================================================================

     1:  Y31 = (1-A1)*(C0+C1*TX2HI)*(LAUCPI/MOPS)+A1-A1*(D0+D1*REGION)*(OHSEPI/MOPS)

     NOB = 48      NOVAR = 5
     RANGE =  1 TO 48
     RSQ =    0.36572      CRSQ =    0.30672      F(4/43) =      6.198
     SER =    0.0474       SSR = 9.653E-02      DW(0) =  2.24     COND(X) =     30.66
     LHS MEAN =       0.50300     SR =          0.

     COEF           VALUE          ST ER          T-STAT         MEAN

     A1            0.42462        0.04504        9.42735        1.55449
     C0          -21.09430       12.46690       -1.69203        0.00618
     C1            0.01865        0.00647        2.88464        2.14549
     D0          -32.13680       16.82930       -1.90957       -0.00456
     D1          -10.13580        4.97639       -2.03677       -0.00221

     COEF          PARTIAL          BETA

     A1            0.82093        0.71745
     C0           -0.24985       -0.52359
     C1            0.40267        0.38970
     D0           -0.27959       -0.53683
     D1           -0.29663       -0.37297

                             COVARIANCE MATRIX

     A1           2.029E-03
     C0          -2.613E-01     1.554E+02
     C1           6.704E-05    -1.176E-02     4.181E-05
     D0           2.752E-01     1.331E+02     2.355E-02     2.832E+02
     D1           1.731E-01    -3.406E+01     5.615E-03     3.250E+00     2.476E+01

==========================================================================================
```

relation. A comparison of the specification shown in Table 4-17 with a model in which the coefficients C1 and D1 are restricted to zero results in an F-test statistic of 7.295, which is greater than the critical value of 2.44. Thus, we reject the null hypothesis that the two coefficients should be restricted to zero.

The elasticities of demand with respect to TSP are 0.079 and -0.079 for laundry/cleaning products and other household products, respectively.* The own-price elasticities of demand are -1.182 for laundry/cleaning products and -1.332 for other household products.

Home Furnishings and Equipment—

This disaggregate demand system includes four goods: household textiles, furniture, major and minor appliances, and housewares. A distinguishing feature of the goods included in this demand system is that they can be thought of as being durable goods. The existence of durable economic goods often poses a problem for the researcher. In many instances, an appropriate separability assumption is introduced so that durable goods can be excluded from the analysis. Other options include constructing measures of the flow of services provided by the durable goods, or simply treating purchases of durables as current consumption items.

---

* In a model with TSP entered in both translating terms, the elasticity of laundry/cleaning demand with respect to TSP is 0.089. Similarly, with the logarithm of TSP entered as a single translating parameter, the elasticity is 0.063. All elasticities were statistically significant.

In the present case, the latter approach has been adopted. In part, this assumption seemed reasonable since the data consist of average household expenditures across all households in a particular SMSA.

Table 4-18 presents the final specification for this demand system. As the equations show, higher concentrations of SO_2 lead to increased demand for household textiles. This finding is supported by evidence cited in the Criteria Document (5) that cottons and nylons are subject to damage by acids derived from SO_2. *A priori*, it also seemed reasonable to expect that higher levels of TSP would lead to increased soiling of fabrics and consequently increased cleaning, and possibly more frequent replacement because of wear and tear. While the signs of the TSP coefficients were as expected, several specifications with TSP included did not lead to coefficients that were significantly different from zero.

The demand elasticity with respect to SO_2 for household textiles is 0.100. This implies that a 10 percent reduction in SO_2 concentrations leads to a 1 percent reduction in the demand for home textile products.

The equation results recorded in Table 4-18 have several restrictions imposed on the E/D variables. In particular, note that a translating parameter for SO_2 is defined only for household textiles. Other restrictions involve the appearance of the family size and

TABLE 4-18. LES FURNISHINGS DEMAND SYSTEM

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====================================================================================================

 1:     Y41 = (1-H1)*(E0+E2*SX2HI)*(HTEXPI/MOUSE)+H1-H1*((F0+F1*FAMSZ+F3*REGION)*(FURNPI/MOUSE)+(C0+C1*FAMSZ+
        C3*REGION)*(APPPI/MOUSE)+G0*(HWARPI/MOUSE))

 2:     Y42 = (1-B1)*(F0+F1*FAMSZ+F3*REGION)*(FURNPI/MOUSE)+B1-B1*((E0+E2*SX2HI)*(HTEXPI/MOUSE)+(C0+C1*FAMSZ+
        C3*REGION)*(APPPI/MOUSE)+G0*(HWARPI/MOUSE))

 3:     Y43 = (1-A1)*(C0+C1*FAMSZ+C3*REGION)*(APPPI/MOUSE)+A1-A1*((E0+E2*SX2HI)*(HTEXPI/MOUSE)+(F0+F1*FAMSZ+
        F3*REGION)*(FURNPI/MOUSE)+G0*(HWARPI/MOUSE))


          CONVERGENCE OBTAINED

          CONVERGENCE ON S OBTAINED

          MODEL: HOUSE   NOB = 48   NOVAR = 12   NOEQ = 3
          OPT ALGORITHM: DAVIDON-FLETCHER-POWELL
          OPT OPTIONS:  RADIUS = 1.         CONCR = 0.001      ITER LIMIT = 10
          INITIAL S MATRIX:  RESIDUALS CALCULATED FROM INITIAL COEFFICIENT ESTIMATES
          ITERATIVE 3SLS SELECTED:  ITER LIMIT = 25   CONCR = 1.000000E-05
          INITIAL H-INVERSE:  DEFAULT START

           COEF            VALUE           STD ERR          T-STAT

           B1               0.577214        0.035254        16.3728
           F1             -37.9175         21.8754          -1.73333
           E2               0.014263        0.004251         3.355
           C3               1.62705         7.68769          0.211644
           C1              10.3385         13.828            0.747653
           F3              54.1738         14.7429           3.67456
           C0             -49.5654         42.5064          -1.16607
           G0              -7.61987         4.0973          -1.85973
           F0             -22.8435         76.1183          -0.300105
           E0               2.95998         8.84983          0.334467
           H1               0.106809        0.017239         6.19587
           A1               0.248762        0.032301         7.70146

          SINGLE EQUATION STATISTICS

          |============|================|================|================|================|
          |            |       RSQ      |      CRSQ      |       SSR      |       DW       |
          |============|================|================|================|================|
          | EQN 1      |       0.326074 |       0.16646  |       0.029813 |       2.58348  |
          | EQN 2      |       0.322683 |       0.162266 |       0.131887 |       2.52661  |
          | EQN 3      |       0.163355 |      -0.034797 |       0.133312 |       2.45107  |
          |============|================|================|================|================|

====================================================================================================
```

region variables. The likelihood ratio test between this specification and a model where all E/D coefficients are restricted to zero results in a test statistic of 9.28. Since this statistic is greater than the critical value at the 10 percent confidence level, we reject the null hypothesis and adopt the less restricted model.

The own-price elasticities of demand are -0.848 for textiles, -1.284 for furnishings, -1.182 for appliances, and -1.370 for housewares. As with some of the earlier groups that have been discussed, we have not seen previous demand studies with a breakdown like that used here. However, Abbott and Ashenfelter (64) report own-price elasticities in the range of -0.601 to -1.525 for an aggregate durable goods category. Our estimates fall within the range of these elasticities.

Clothing--

The clothing disaggregate demand system is a two-good system comprised of clothing and dry cleaning. Table 4-19 reports the final specification for this system. The included E/D variables are family size and temperature. Temperature replaced the region dummy in this specification because its more precise locational definition provided a better fit in explaining the share of expenditures on clothing. The signs of the family size and temperature coefficients are both plausible. The estimated equation indicates that as family size increases, expenditure on clothing increases. Similarly, as temperature increases, expenditure on clothing decreases.

TABLE 4-19. LES CLOTHING DEMAND SYSTEM

```
==============================================================================

11  Y51 = (1-B1)*(C0+C2*FAMSZ+C3*TEMP)*(MCLOPI/MCLOTH)+B1-B1*D0*(DRYCPI/MCLOTH)

NOB = 48     NOVAR = 5
RANGE =  1 TO 48
RSQ =   0.24923     CRSQ =   0.17939     F(4/43) =     3.569
SER =   0.0251      SSR = 2.715E-02      DW(0) =  2.03     COND(X) =    56.97
LHS MEAN =      0.86612     SR =      0.00006

COEF           VALUE          ST ER        T-STAT         MEAN

B1            0.85079        0.02639       32.23310       1.20395
C0         -579.79500      334.64500       -1.73257   2.26277E-04
C2          205.28800       79.65830        2.57711   6.38529E-04
C3           -7.86548        3.87677       -2.02888       0.00299
D0          -29.94560       15.03390       -1.99188      -0.00130

COEF          PARTIAL          BETA

B1            0.97993        2.71186
C0           -0.25545       -0.70197
C2            0.36577        0.86122
C3           -0.29558       -0.34179
D0           -0.29065       -0.38989

                       COVARIANCE MATRIX

B1          6.967E-04
C0         -6.981E+00      1.120E+05
C2          1.127E+00     -2.356E+04      6.345E+03
C3         -2.895E-02      3.985E+02     -1.363E+02      1.503E+01
D0         -9.305E-02      2.410E+03     -2.675E+02      1.065E+01      2.260E+02

==============================================================================
```

A priori, one might expect TSP to influence the demand for both of these items. However, this was not substantiated in the estimation. The best fit achieved was a quadratic specification for the maximum of annual geometric means for TSP. This specification indicated that higher concentrations of TSP lead to higher expenditures on dry cleaning when the equation is evaluated at the means of the variables. The F-test for the models with and without the TSP variables resulted in a statistic less than the critical F-value at the 10 percent level of significance.* Thus, we fail to reject the null hypothesis that the TSP coefficients should be restricted to zero.

One possible explanation as to why a pollution effect is not observed in this demand system is that both goods may be positively related to TSP or SO_2. Consequently, given the expenditure constraint implicit in the system, the effect for either of the goods may not be easily identified. In order to test this hypothesis, several single equation, multiplicative specifications were run that did not include the constraints mentioned above as a part of the set of maintained assumptions. Again, no statistically significant relationship was observed between any of the pollution measures and clothing or dry cleaning. Consequently, given this data set, one cannot justify including pollution variables in the clothing demand system.

---

* The value of the F-test was 1.36, while the critical value with (2,41) degrees of freedom is approximately 2.44 at the 10 percent significance level.

The own-price elasticities for the specification shown in Table 4-19 are -1.027 and -1.283 for clothing and dry cleaning, respectively. Our elasticity for clothing is lower than that reported by Pollak and Wales (43) for a generalized translog and quadratic expenditure system, which were in the range -1.3 to -1.7. However, our elasticity is also slightly higher than the elasticities reported by these authors for an LES specification [Reference (41), elasticity for clothing equal to about -0.90].

Transportation--

The sixth disaggregate demand system involves expenditures for transportation purposes. The two goods included in this system are gas and fuel, and "other vehicle operations". The latter good includes items such as lubricants, filters, tires, batteries, body work, and electrical work.

A priori, one might expect TSP or SO_2 to affect the demand for both of these goods. For example, acids from SO_2 may add to corrosion of metal surfaces, while high concentrations of TSP may hinder vehicle performance because of particle accumulations in engine parts.

The demand for gas and fuel may also be directly related to pollution levels. For example, over time, people may decide to reside further away from highly polluted central city areas in order to ameliorate the disamenity affects of pollution at their residence. In this case, they exhibit a willingness to trade off increased gas and fuel costs for a cleaner environment at their homes.*

SO_2 and TSP were included in several specifications for this demand system. While the coefficient for TSP was always statistically insignificant, a significant, positive relation was observed between SO_2 and the demand for gas and fuel.

The final specification for this system is shown in Table 4-20. The E/D variables included in the equation are the maximum second-high concentration of SO_2 and temperature. Alternative models with family size and region did not support the inclusion of these variables. The coefficient for temperature is positive, which indicates that there is a direct relation between temperature and the demand for gas and fuel. This seems plausible for at least two reasons. First, the use of automobile air conditioners is likely to increase in warmer areas, which could result in a loss of fuel efficiency, and consequently more expenditures for gasoline. Second, warmer temperatures might also lead to more frequent outdoor, away from home activities.

The demand elasticities with respect to SO_2 are 0.038 and -0.034 for gas and fuel and other vehicle operations, respectively.** The

---

* Note that this effect is consistent with the notion that certain long-run adjustments have already been made.

** When SO_2 is entered in both translating terms, the elasticity of gas and fuel demand with respect to SO_2 is 0.039. With SO_2 entered logarithmically, the elasticity is also 0.039. In each of the specifications, the elasticities were statistically significant.

TABLE 4-20. LES TRANSPORTATION DEMAND SYSTEM

```
=====================================================================================

  3!  Y61 = (1-A1)*(C0+C1*TEMP+C2*SX2HI)*(VHGFPI/MTRANS)+A1-A1*(D0+D1*TEMP)*(VEHOPI/MTRANS)

  NOB = 48     NOVAR = 6
  RANGE =  1 TO 48
  RSQ =    0.40689     CRSQ =    0.33628      F(5/42) =      5.763
  SER =    0.0294      SSR = 3.639E-02       DW(0) =  2.70      COND(X) =   176.41
  LHS MEAN =       0.43998      SR =        0.00001

  COEF            VALUE          ST ER          T-STAT           MEAN

  A1            0.53605        0.02352        22.78670          1.22914
  C0         -630.84400      267.86900        -2.35505      6.16862E-04
  C1           33.85520       19.13490         1.76929          0.00797
  C2            0.06335        0.02650         2.39050          0.28136
  D0         -340.01100      231.87200        -1.46637     -7.12453E-04
  D1           25.69270       16.34640         1.57176         -0.00921

  COEF            PARTIAL         BETA

  A1            0.96185        5.00691
  C0           -0.34154       -2.37566
  C1            0.26337        2.46362
  C2            0.34607        0.43709
  D0           -0.22069       -1.39285
  D1            0.23570        2.19107

                          COVARIANCE MATRIX

  A1          5.534E-04
  C0         -3.849E-01     7.175E+04
  C1         -1.020E-02    -4.863E+03     3.661E+02
  C2          2.517E-04    -2.063E+00     1.068E-01     7.023E-04
  D0          1.423E+00     5.839E+04    -4.073E+03    -4.436E-01     5.376E+04
  D1         -6.508E-02    -4.027E+03     3.077E+02     4.328E-02    -3.595E+03     2.672E+02
=====================================================================================
```

own-price elasticities are -1.220 and -1.000 for these goods. The estimates of own-price elasticity are within the range of elasticities reported by Abbott and Ashenfelter (64) (-0.571 to -1.439) for transportation services.

Personal Care--

Table 4-21 reports the results for the final specification of the personal care disaggregate demand system. The three goods included in this system are non-insured medical care, prescription drugs, and personal care items. Since all three of these items are related to health expenditures, there is a basis for suspecting that increased levels of air pollutants may lead to higher demands for these items.

However, estimation of the demand system does not support the hypothesis that TSP or SO_2 should be included in the equations. For example, with a translating parameter for TSP added to each translating expression in the system, the test statistic, relative to the case where each TSP translating parameter is zero, is 2.37. Since this is less than the critical value of 6.25, we fail to reject the null hypothesis. On the other hand, a comparison of the specification shown in Table 4-21 with a completely restricted model leads to a test statistic of 9.28, which is greater than the 10 percent chi-square critical value. Therefore, we reject the null hypothesis.

There are two possible reasons for the statistical insignificance of the pollution variables in this system. First, if all three goods

TABLE 4-21. LES PERSONAL CARE DEMAND SYSTEM

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==========================================================================================

   1:      Y73 = (1-A1)*(C0+C1*REGION)*(PERSPI/MCARE)+A1-A1*((D0+D1*REGION+D2*FAMSZ)*(NPREPI/MCARE)+(E0+E1*
           REGION)*(NINSPI/MCARE))

   2:      Y72 = (1-B1)*(D0+D1*REGION+D2*FAMSZ)*(NPREPI/MCARE)+B1-B1*((C0+C1*REGION)*(PERSPI/MCARE)+(E0+E1*
           REGION)*(NINSPI/MCARE))


            CONVERGENCE OBTAINED

            CONVERGENCE ON S OBTAINED

            MODEL: PCARE   NOB = 48   NOVAR = 9   NOEQ = 2
            OPT ALGORITHM: DAVIDON-FLETCHER-POWELL
            OPT OPTIONS:  RADIUS = 1.          CONCR = 0.001        ITER LIMIT = 10
            INITIAL S MATRIX:  RESIDUALS CALCULATED FROM INITIAL COEFFICIENT ESTIMATES
            ITERATIVE 3SLS SELECTED:  ITER LIMIT = 25   CONCR = 1.000000E-05
            INITIAL H-INVERSE:  DEFAULT START

             COEF            VALUE           STD ERR           T-STAT

             B1              0.120478         0.017761          6.7832
             D1             33.4978          17.8299            1.87874
             C0            -26.6643          27.3694           -0.974235
             E0           -261.357           85.7471           -3.048
             D0             -4.10299         39.8915           -0.102854
             C1             39.633           36.0813            1.09844
             A1              0.244553         0.03445           7.09876
             D2            -17.0147          13.8771           -1.22609
             E1            128.892           98.8287            1.3042

            SINGLE EQUATION STATISTICS

            |===========|===============|===============|===============|===============|
            |           |      RSQ      |     CRSQ      |      SSR      |      DW       |
            |===========|===============|===============|===============|===============|
            | EQN 1     |      0.431308 |      0.331786 |      0.050192 |     2.0084    |
            | EQN 2     |      0.215451 |      0.078155 |      0.063563 |     2.25434   |
            |===========|===============|===============|===============|===============|

==========================================================================================
```

are directly affected by TSP or SO_2, the constraints imposed through the system estimation may conceal air pollution effects for any one good. However, as before, single-equation regressions for each good did not support this hypothesis. Alternatively, it may be that the three goods are defined at too aggregate a level so that any air quality effects for a particular good are not easily identified. This is a real possibility in this demand system, since personal care items encompass over 50 items while non-prescription drugs is defined for about 30 separate items. In each case, some of the goods in the group may be affected by high concentrations of TSP or SO_2, while others may not.

The own-price demand elasticities for the equations shown in Table 4-21 are -1.256, -1.541, and -1.024 for non-insured medical care, non-prescription drugs, and personal care items, respectively.

Summary of LES Model—

In this subsection, the empirical results for the LES disaggregate demand system have been described. Each equation set has been subjected to a variety of checks in order to gauge the plausibility of the equations presented as final specifications. These checks have included alternative specifications of the way in which the pollution variables are allowed to enter the system, calculation of elasticities of demand with respect to prices and pollution, and where possible, comparison with elasticities taken from the literature. These checks indicate that our final specifications are reasonable.

There is one other set of checks that can be made. This involves estimating a different structural model. In the next subsection, a demand system using equations generated from a homogeneous translog (HTL) indirect utility function is estimated. Estimation of this second system provides another basis for judging the sensitivity of the results. For example, it would be reassuring if the various sets of elasticities we have calculated for the LES are not drastically different from those derived from the HTL model.

Linear Logarithmic Expenditure System

The linear logarithmic expenditure system is derived from an indirect utility function that is a homogeneous transcendental logarithmic function:

$$\ln W = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln p_i^* + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} \ln p_i^* \ln p_j^* \quad (4.29)$$

where W is the indirect utility index, $\beta_{ij} = \beta_{ji}$ for all i and j; p_i^* are normalized prices such that $p_i^* \equiv p_i/M$ (where M is total expenditure); and $\sum_{i=1}^{n} \alpha_i = 1$; $\sum_{i=1}^{n} \beta_{ij} = 0$ for all j.

Individual commodity expenditures can be obtained by using Roy's identity:

$$-p_i^* X_i = \frac{\partial \ln W}{\partial \ln p_i^*} \quad \text{for all } i.$$

Given the form of ln W, this can be rewritten as:

$$-p_i^* X_i = \alpha_i + \sum_{j=1}^{n} \beta_{ij} \ln p_j^* \quad \text{for all } i. \tag{4.30}$$

Lau, Lin and Yotopoulos (45) show that within this framework, E/D variables can be introduced such that the consumption expenditure functions become:

$$-p_i^* X_i = \alpha_i + \sum_{j=1}^{n} \beta_{ij} \ln p_j^* + \sum_{k=1}^{m} \varepsilon_{ik} \ln S_k \quad \text{for all } i \tag{4.31}$$

with the additional restriction $\sum_{i=1}^{n} \varepsilon_{ik} = 0$ for all k, where S_k is the k^{th} E/D variable and m is the number of E/D variables.

This way of introducing E/D variables into a demand system is different from the translating technique used with the LES. The advantage in specifying the system as in Equation (4.34) is that each equation of the system is linear so that estimation and hypothesis testing become easier. Unfortunately, the homogeneity restriction on the E/D variables can lead to difficulties in constructing a meaningful aggregate price index. This problem is discussed more fully in the next subsection.

For estimation purposes, it is convenient to make use of the homogeneity assumption on the indirect utility function. This results in an expenditure function of the form:

$$-p_i^* x_i = \alpha_i + \sum_{j=1}^{n-1} \beta_{ij}\left(\ln p_j^* - \ln p_n^*\right) + \sum_{k=1}^{m} \varepsilon_{ik} \ln S_k \quad \text{for } i = 1, \ldots, n-1 \qquad (4.32)$$

Furthermore, in the reported results, the cross-equation symmetry restrictions $\beta_{ij} = \beta_{ji}$ for all i,j have been imposed.

The feature that sets the HTL specification apart from more general translog forms is the homogeneity assumption. While this assumption is required for the two-stage optimization model to be valid, it does impose restrictions that have an economic interpretation. In particular, the total expenditure elasticity of demand for each good must be unity. Note, however, that because the analysis is concerned with disaggregate subsystems, this does not imply that the income elasticity of demand for each commodity is unity. The latter would seem to be an even more tenuous assumption.

Tables 4-22 through 4-28 present the final specifications for the HTL disaggregate demand system. Note that each of the dependent variables is an expenditure share so that only N-1 equations for each system are estimated. The coefficients of the remaining equation can be derived from the homogeneity and symmetry constraints.

The discussion of the results for the HTL will be limited. Instead of providing a detailed account of the steps undertaken to arrive at a final specification, the emphasis is on comparing the HTL results with those of the LES. Specifically, comparisons are made for the various elasticity measures.

Own-price elasticities of demand for the HTL are presented in Table 4-29. These elasticities are calculated from the relation:

$$\varepsilon_{ii} = \frac{\partial x_i}{\partial p_i} \frac{p_i}{x_i} = -1 - \frac{B_{ii}M}{p_i x_i} \tag{4.33}$$

where B_{ii} is the coefficient for the i^{th} price term in the i^{th} equation, M is total expenditure in the category and x_i is the quantity demanded of the i^{th} good.

TABLE 4-22. HTL FOOD DEMAND SYSTEM

```
==============================================================================================================
1)      -Y11 = A1+B0*(LOG(CEBAPI/MFOOD)-LOG(MISCPI/MFOOD))+B1*(LOG(BEFKPI/MFOOD)-LOG(MISCPI/MFOOD))+B2*(LOG(
        DREGPI/MFOOD)-LOG(MISCPI/MFOOD))+B3*(LOG(FRVEPI/MFOOD)-LOG(MISCPI/MFOOD))+G11*LOG(FAMSZ)+G12*REGION

2)      -Y12 = A2+B1*(LOG(CEBAPI/MFOOD)-LOG(MISCPI/MFOOD))+C1*(LOG(BEFKPI/MFOOD)-LOG(MISCPI/MFOOD))+C2*(LOG(
        DREGPI/MFOOD)-LOG(MISCPI/MFOOD))+C3*(LOG(FRVEPI/MFOOD)-LOG(MISCPI/MFOOD))+G21*LOG(FAMSZ)

3)      -Y13 = A3+B2*(LOG(CEBAPI/MFOOD)-LOG(MISCPI/MFOOD))+C2*(LOG(BEFKPI/MFOOD)-LOG(MISCPI/MFOOD))+D1*(LOG(
        DREGPI/MFOOD)-LOG(MISCPI/MFOOD))+D2*(LOG(FRVEPI/MFOOD)-LOG(MISCPI/MFOOD))+G31*LOG(FAMSZ)

4)      -Y14 = A4+B3*(LOG(CEBAPI/MFOOD)-LOG(MISCPI/MFOOD))+C3*(LOG(BEFKPI/MFOOD)-LOG(MISCPI/MFOOD))+D2*(LOG(
        DREGPI/MFOOD)-LOG(MISCPI/MFOOD))+E1*(LOG(FRVEPI/MFOOD)-LOG(MISCPI/MFOOD))+G42*REGION

          CONVERGENCE OBTAINED

          CONVERGENCE ON S OBTAINED


          MODEL: FOOD2   NOB = 48   NOVAR = 19   NOEQ = 4
          OPT ALGORITHM: DAVIDON-FLETCHER-POWELL
          OPT OPTIONS:  RADIUS = 1.          CONCR = 0.001       ITER LIMIT = 10
          INITIAL S MATRIX:  RESIDUALS CALCULATED FROM INITIAL COEFFICIENT ESTIMATES
          ITERATIVE 3SLS SELECTED:  ITER LIMIT = 25   CONCR = 0.001
          INITIAL H-INVERSE:  DEFAULT START

           COEF              VALUE            STD ERR            T-STAT

           A1              -0.066141          0.015197          -4.35236
           A2              -0.099691          0.051575          -1.93295
           A3              -0.190703          0.020229          -9.42732
           A4              -0.124933          0.001963         -63.4417
           B1              -0.034032          0.019753          -1.72293
           B2               0.023512          0.01118            2.10308
           B3              -0.016716          0.013065          -1.27942
           C1               0.062448          0.057094           1.09377
           C2              -0.025485          0.021891          -1.16419
           C3               0.015628          0.019193           0.81425
           D0               0.024561          0.017311           1.41878
           D1               0.039408          0.016034           2.45782
           D2               0.036005          0.013393           2.68839
           E1              -0.002269          0.02096           -0.108275
           G11             -0.023463          0.014884          -1.57638
           G12             -0.006913          0.002198          -3.14479
           G21             -0.188362          0.049768          -3.78479
           G31              0.061021          0.019522           3.12581
           G42              0.010271          0.002796           3.67349

          SINGLE EQUATION STATISTICS

          |============|================|================|================|================|
          |            |            RSQ |           CRSQ |            SSR |        DW      |
          |============|================|================|================|================|
          | EQN 1      |       0.336605 |       0.239523 |       0.002588 |   2.09936      |
          | EQN 2      |       0.280065 |       0.194358 |       0.03124  |   2.252        |
          | EQN 3      |       0.386082 |       0.312996 |       0.00477  |   2.21637      |
          | EQN 4      |       0.333065 |       0.253668 |       0.003722 |   1.96285      |
          |============|================|================|================|================|
==============================================================================================================
```

TABLE 4-23. HTL SHELTER DEMAND SYSTEM

```
================================================================================================

    3:  -Y21 = A1+B1*(LOG(RPRPI/MSHELTER)-LOG(UTILPI/MSHELTER))+D1*LOG(SX2HI)+E1*LOG(TX2HI)

    NOB = 48      NOVAR = 4
    RANGE =   1 TO 48
    RSQ =    0.28418      CRSQ =    0.23537      F(3/44) =      5.823
    SER =    0.0294       SSR = 3.810E-02        DW(0) =   2.51      COND(X) =     32.05
    LHS MEAN =      -0.25069      SR =       -0.

    COEF            VALUE          ST ER          T-STAT          MEAN

    A1            -0.32836        0.06129        -5.35769        1.00000
    B1             0.05512        0.02013         2.73829       -0.01268
    D1            -0.01540        0.00623        -2.47340        5.79377
    E1             0.02913        0.00952         3.06133        5.75303

    COEF            PARTIAL        BETA

    A1            -0.62834        0.00000
    B1             0.38158        0.38729
    D1            -0.34938       -0.35338
    E1             0.41904        0.39490

                           COVARIANCE MATRIX

    A1             3.756E-03
    B1             2.898E-04      4.051E-04
    D1            -1.763E-04     -5.396E-05      3.876E-05
    E1            -4.715E-04      4.852E-06     -8.506E-06      9.054E-05

================================================================================================
```

TABLE 4-24. HTL HOME OPERATIONS DEMAND SYSTEM

```
==========================================================================

31  -Y31 = A1+B1*(LOG(LAUCPI/MOPS)-LOG(OHSEPI/MOPS))+C1*LOG(TX2HI)

NOB = 48     NOVAR = 3
RANGE =  1 TO 48
RSQ =   0.31463     CRSQ =   0.28417     F(2/45) =    10.329
SER =   0.0481      SSR =     0.104      DW(0) =  2.21     COND(X) =    26.08
LHS MEAN =      -0.50300     SR =      -0.

COEF            VALUE          ST ER         T-STAT         MEAN

A1            -0.21741        0.09069       -2.39712        1.00000
B1             0.17469        0.06819        2.56171       -0.00226
C1            -0.04957        0.01572       -3.15275        5.75303

COEF           PARTIAL         BETA

A1            -0.33650        0.00000
B1             0.35675        0.32293
C1            -0.42535       -0.39746

                         COVARIANCE MATRIX

A1            8.226E-03
B1           -1.248E-03      4.651E-03
C1           -1.422E-03      2.187E-04      2.472E-04

==========================================================================
```

TABLE 4-25. HTL FURNISHINGS DEMAND SYSTEM

```
=====================================================================================

1:      -Y41 = A1+B1*(LOG(HTEXPI/MOUSE)-LOG(HWARPI/MOUSE))+B2*(LOG(FURNPI/MOUSE)-LOG(HWARPI/MOUSE))+B3*(LOG(
        APPPI/MOUSE)-LOG(HWARPI/MOUSE))+G12*LOG(SX2HI)

2:      -Y42 = A2+B2*(LOG(HTEXPI/MOUSE)-LOG(HWARPI/MOUSE))+C2*(LOG(FURNPI/MOUSE)-LOG(HWARPI/MOUSE))+C3*(LOG(
        APPPI/MOUSE)-LOG(HWARPI/MOUSE))+G21*LOG(FAMSZ)+G23*REGION

3:      -Y43 = A3+B3*(LOG(HTEXPI/MOUSE)-LOG(HWARPI/MOUSE))+C3*(LOG(FURNPI/MOUSE)-LOG(HWARPI/MOUSE))+D3*(LOG(
        APPPI/MOUSE)-LOG(HWARPI/MOUSE))+G31*LOG(FAMSZ)+G33*REGION

         CONVERGENCE OBTAINED

         CONVERGENCE ON S OBTAINED

         MODEL: FURN2   NOB = 48   NOVAR = 14   NOEQ = 3
         OPT ALGORITHM: DAVIDON-FLETCHER-POWELL
         OPT OPTIONS:  RADIUS = 1.         CONCR = 0.001       ITER LIMIT = 10
         INITIAL S MATRIX:  RESIDUALS CALCULATED FROM INITIAL COEFFICIENT ESTIMATES
         ITERATIVE 3SLS SELECTED:  ITER LIMIT = 25   CONCR = 1.000000E-05
         INITIAL H-INVERSE:  DEFAULT START

          COEF            VALUE           STD ERR          T-STAT

          A1            -0.098823        0.018691        -5.28724
          A2            -0.66472         0.10311         -6.44673
          A3            -0.050887        0.101549        -0.501107
          B1            -0.037157        0.029357        -1.26569
          B2            -0.04906         0.020531        -2.38956
          B3             0.033515        0.02982          1.12393
          C2             0.143078        0.045535         3.14216
          C3            -0.056672        0.040672        -1.39339
          D3             0.069367        0.048294         1.43634
          G12           -0.013856        0.003157        -4.38927
          G21            0.217398        0.101078         2.1508
          G31           -0.248439        0.099599        -2.4944
          G33            0.048168        0.016826         2.86277
          G23           -0.058521        0.017098        -3.42269

         SINGLE EQUATION STATISTICS

         |============|================|================|================|================|
         |            |       RSQ      |       CRSQ     |       SSR      |       DW       |
         |============|================|================|================|================|
         | EQN 1      |       0.33094  |       0.268701 |       0.029598 |        2.32095 |
         | EQN 2      |       0.270172 |       0.183288 |       0.142112 |        2.39688 |
         | EQN 3      |       0.181812 |       0.084409 |       0.130371 |        2.37172 |
         |============|================|================|================|================|
=====================================================================================
```

TABLE 4-26. HTL CLOTHING DEMAND SYSTEM

```
=====================================================================================

      4:  -Y51 = A1+B1*(LOG(MCLOPI/MCLOTH)-LOG(DRYCPI/MCLOTH))+C1*LOG(FAMSZ)+C2*LOG(TEMP)

      NOB = 48     NOVAR = 4
      RANGE =  1 TO 48
      RSQ =   0.24334     CRSQ =   0.19175     F(3/44) =      4.717
      SER =   0.0249      SSR = 2.736E-02      DW(0) =  2.09      COND(X) =     33.94
      LHS MEAN =      -0.86612     SR =      -0.

      COEF            VALUE          ST ER         T-STAT          MEAN

      A1            -0.79198        0.05461      -14.50350        1.00000
      B1             0.04221        0.01824        2.31434        0.01879
      C1            -0.12728        0.04669       -2.72623        1.03320
      C2             0.02237        0.01153        1.94079        2.52882

      COEF           PARTIAL         BETA

      A1            -0.90940        0.00000
      B1             0.32943        0.30627
      C1            -0.38014       -0.36135
      C2             0.28081        0.25540

                              COVARIANCE MATRIX

      A1             2.982E-03
      B1             8.019E-05     3.326E-04
      C1            -2.151E-03    -1.092E-04     2.180E-03
      C2            -2.957E-04     1.041E-05    -3.909E-05     1.328E-04

=====================================================================================
```

TABLE 4-27. HTL TRANSPORTATION DEMAND SYSTEM

```
=====================================================================================
   1:  -Y61 = A1+B1*(LOG(VHGFPI/MTRANS)-LOG(VEHOPI/MTRANS))+D1*LOG(TEMP)


   NOB = 48     NOVAR = 3
   RANGE =  1 TO 48
   RSQ =    0.09747     CRSQ =    0.05736     F(2/45) =      2.430
   SER =    0.0351      SSR = 5.538E-02       DW(0) =  2.39     COND(X) =    16.20
   LHS MEAN =      -0.43998     SR =      -0.

   COEF             VALUE           ST ER         T-STAT           MEAN

   A1             -0.36020        0.04118       -8.74765         1.00000
   B1              0.05625        0.05671        0.99179    -8.29220E-04
   D1             -0.03153        0.01616       -1.95097         2.52882


   COEF             PARTIAL         BETA

   A1             -0.79353        0.00000
   B1              0.14626        0.14048
   D1             -0.27926       -0.27635


                             COVARIANCE MATRIX

   A1              1.696E-03
   B1             -3.679E-05      3.216E-03
   D1             -6.604E-04      1.560E-05      2.611E-04
=====================================================================================
```

TABLE 4-28. HTL PERSONAL CARE DEMAND SYSTEM

```
=================================================================================

 1:      -Y73 = A1+G11*REGION+C0*(LOG(PERSPI/MCARE)-LOG(NINSPI/MCARE))+C1*(LOG(NPREPI/MCARE)-LOG(NINSPI/MCARE)
         )

 2:      -Y72 = A2+G21*REGION+G22*LOG(FAMSZ)+C1*(LOG(PERSPI/MCARE)-LOG(NINSPI/MCARE))+D1*(LOG(NPREPI/MCARE)-
         LOG(NINSPI/MCARE))


            CONVERGENCE OBTAINED

            CONVERGENCE ON S OBTAINED


            MODEL: PCARE1   NOB = 48   NOVAR = 8   NOEQ = 2
            OPT ALGORITHM: DAVIDON-FLETCHER-POWELL
            OPT OPTIONS:  RADIUS = 1.          CONCR = 0.001       ITER LIMIT = 10
            INITIAL S MATRIX:  RESIDUALS CALCULATED FROM INITIAL COEFFICIENT ESTIMATES
            ITERATIVE 3SLS SELECTED:  ITER LIMIT = 25   CONCR = 0.0001
            INITIAL H-INVERSE:  DEFAULT START

             COEF           VALUE          STD ERR          T-STAT

             A1           -0.363654        0.007886       -46.1123
             C0            0.095931        0.033448         2.86804
             C1           -0.056156        0.020287        -2.76805
             D1            0.044818        0.024475         1.83118
             G11           0.026544        0.010714         2.47761
             G22           0.119978        0.071453         1.6791
             G21          -0.017466        0.011218        -1.55698
             A2           -0.221555        0.072938        -3.03759

            SINGLE EQUATION STATISTICS

            |============|================|================|================|================|
            |            |            RSQ |           CRSQ |            SSR |             DW |
            |============|================|================|================|================|
            | EQN 1      |       0.284184 |       0.235378 |       0.063177 |        2.1672  |
            | EQN 2      |       0.199346 |       0.124867 |       0.064868 |        2.09689 |
            |============|================|================|================|================|

=================================================================================
```

TABLE 4-29. OWN-PRICE ELASTICITIES OF DEMAND

Category	HTL system	LES system
Food		
a. Cereal and bakery products	-1.260	-1.245
b. Meats	-1.211	-1.079
c. Dairy products	-1.309	-1.159
d. Fruits and vegetables	-0.981	-0.985
e. Miscellaneous foods	-1.337	-1.041
Shelter		
a. Home repair	-1.220	-1.126
b. Utilities	-1.074	-1.067
Home operations		
a. Laundry/cleaning products	-1.348	-1.182
b. Other household products	-1.351	-1.332
Furnishings and equipment		
a. Textiles	-0.792	-0.848
b. Furniture	-1.300	-1.284
c. Appliances	-1.249	-1.182
d. Housewares	-1.462	-1.370
Clothing		
a. Clothing	-1.049	-1.027
b. Dry cleaning	-1.314	-1.283
Transportation		
a. Gas and fuel	-1.128	-1.220
b. Other vehicle operations	-1.101	-1.000
Personal care		
a. Non-insured medical care	-1.278	-1.256
b. Non-prescription drugs	-1.412	-1.541
c. Personal care	-1.052	-1.024

The own-price elasticities for the LES system are also included in Table 4-29. As can be seen from the table, there is good agreement between the calculated own-price elasticities of the two systems.

Another important check that can be made is with respect to the elasticity between demand and the pollution variables. Since it is these elasticities which play a crucial role in determining the benefits associated with an improvement in air quality, it would be reassuring to find similar results for the two systems. Table 4-30 presents the results for this plausibility check. As with the own-price elasticities of demand, there was good correspondence between the results of the two models. In general, the HTL elasticities are

TABLE 4-30. ELASTICITIES BETWEEN DEMAND AND THE POLLUTION VARIABLES

Category	HTL system	LES system
Shelter		
a. Home repairs (SO_2)	0.062	0.061
b. Utilities (TSP)	0.039	0.025
Home operations		
a. Laundry/cleaning products (TSP)	0.099	0.079
Furnishings and equipment		
a. Textiles (SO_2)	0.078	0.100
Transportation		
a. Gas and fuel (SO_2)	--*	0.038

* SO_2 not a statistically significant variable.

slightly larger than those observed from the LES system, but the differences do not seem extraordinary.

The checks discussed so far use information obtained only from the estimated parameters of the two disaggregate demand models. Another component of the plausibility analysis could focus on the implied effect of the air pollution measures on the price indices developed for the aggregate stage of the two-stage budgeting problem. This is the next topic considered.

Derivation of Aggregate Price Index

Once the parameters of the disaggregate demand systems have been estimated, the next step is to construct consistent aggregate price indices. In the model development subsection, the assumptions that are required for the existence of these indices were described. Here, those results are applied to the specific functional forms that have been analyzed. The objective in forming these indices is to develop the information that is needed to estimate the aggregate stage system.

The construction of these price indices also provides another means of checking the plausibility of the role of air pollution measures in our models. In particular, air pollution measures have been found to be statistically significant variables in four of the disaggregate demand systems. Thus, the four aggregate price indices developed from these subsystems will be functions of air quality. A *priori*, the expectation is that as air quality improves, the aggregate price index should fall since the cost of providing a given unit of cleanliness (or some other service flow) should be lower.

LES System--

In the LES system, outputs are characterized by a function of the form:

$$(x_1 - s_1)^{b_1} \cdot (x_2 - s_2)^{b_2} \ldots (x_n - s_n)^{b_n} \qquad (4.34)$$

where each of the variables are as defined previously. There are two characteristics of this function which are important for defining an aggregate index. First, Equation (4.34) is affinely homothetic. This means that the function is homothetic to the point $(s_1, s_2, \ldots, s_n)$. Second, since the b_i's sum to unity, the function is linearly homogeneous. Given these two characteristics, it is convenient to define an aggregate quantity index in the same form as Equation (4.34). With the quantity index defined in this way, the aggregate price index is defined such that the product of the price and quantity indices equals total group expenditure. This leads to an aggregate price index of the form:

$$P_i = \left[\frac{M_i}{(x_{i1}-s_{i1})}\right]^{b_1} \cdot \left[\frac{M_i}{(x_{i2}-s_{i2})}\right]^{b_2} \ldots \left[\frac{M_i}{(x_{in}-s_{in})}\right]^{b_n} \qquad (4.35)$$

where P_i is the aggregate price index for the i^{th} category.

M_i is total expenditure in the i^{th} category.

$(x_{ij}-s_{ij})$ is the quantity demanded net of variations implied by the translating parameters for the j^{th} good in the i^{th} commodity group.

b_i is the marginal budget share.

n indexes the number of disaggregate goods in the i^{th} commodity group.

The immediate interest with Equation (4.35) is to identify the role of air pollution in the price index. Air quality variables enter Equation (4.35) through the s_{ij}. Clearly, if all estimated parameters for SO_2 or TSP in a given system are positive, then a reduction in concentrations will lead unequivocally to a decrease in the aggregate price index. Will this always be the case?

The manner in which the translating parameters are introduced in the LES system implies that a positive effect of a translating variable for one good in a demand system must be counterbalanced by an equivalent negative effect elsewhere in the system. Thus, in a two-good system, with TSP entered as a translating variable for both goods, the estimated coefficients for TSP must have different signs. Returning to Equation (4.35), this implies that the direction of change of the price index for an air quality improvement depends on the relative sizes of the marginal budget shares.

In the LES system results reported earlier, the air pollution variables are included as translating terms only for those goods whose demands are affected directly by pollution. For example, in the home operations system, TSP was included in the translating expression for laundry/cleaning products, while it did not appear for other household products. The constraint on fixed expenditures is maintained, since the intercept term of the translating expression for other household products picks up the required offsetting effect.

The question here is whether TSP in and of itself is expected to lead to a change in the demand for "other household products". The basis for an adequate answer is, in part, limited to available prior information. In particular, the Criteria Document (5) does not present evidence that the types of goods included in "other household products" would be affected by changes in air quality. This prior information provides one rationale for adoption of a restricted model.

Alternatively, it should be noted that specifications with pollution variables appearing in all translating expressions were generally not supported by statistical tests. In particular, comparisons with models in which some of the air quality coefficients were restricted to zero typically resulted in a failure to reject the null hypothesis; that is, the restrictions were warranted.

It should be stressed that the observations made above do not invalidate Equation (4.35) as a meaningful price index. Rather, they indicate that care must be taken when attempts are made to analyze the effects of changes in certain variables on the aggregate price index.

Given the parameter estimates of the LES system, one statistic of interest involves the predicted average percent change in aggregate price per unit decrease in the air quality measures. For TSP, this value was -0.008 percent for both the shelter and home operations aggregate categories. Similarly, the average percent change in the aggregate price index for a unit decrease in SO_2 concentrations was -0.002, -0.003, and -0.005 percent for the shelter, furnishings, and transportation aggregate goods, respectively.* Each of these values is of the anticipated sign and the magnitudes are not offensive to prior intuition.

HTL System--

Following Lau, Lin, and Yotopolous (45), an aggregate price index for the HTL can be defined as:

$$\ln P_i = \sum_{k=1}^{n} w_k \ln P_k^* \qquad (4.36)$$

where P_i is the aggregate price index for the i^{th} category, w_k is the share of the k^{th} good in the disaggregate system, p_k is the fixed price of the k^{th} good, and n indexes the number of goods in the disaggregate group.

---

* The total change in price for a change in air quality consistent with attainment of the secondary standards generally resulted in price changes of less than $0.01. The maximum observed change in price was approximately $0.015.

As air quality changes, the shares adjust so that their sum is always unity. Since the shares are weighted by the fixed prices, the direction of change in P_i for an improvement in air quality depends solely on the relative prices of the goods in the system. Thus, in a two-good system, if a decrease in concentration levels leads to a decrease in expenditures in the first equation of the system, P_i will decrease only if the price of the first good (i.e., the good for which the expenditure share in the first equation is defined) is greater that the price of the second good. The possibility that P_i can move in any direction with an improvement in air quality runs counter to our a priori expectations that P_i should decrease in such a case.

An explanation as to why this may occur is related to the way in which air pollution variables are introduced in the HTL specification. In particular, if one looks at the subfunction which generates the share equations and ultimately the aggregate indices, it is apparent that the terms involving pollution variables in the share equations are price dependent. That is, they are generated from price interaction terms in the main subfunction. This subfunction can be written as:

$$\ln w = a_0 + \sum_j^n a_j \ln p_j^* + \sum_t^r b_t \ln q_t$$

$$+ \frac{1}{2} \sum_j^n \sum_k^n c_{jk} \ln p_j^* \ln p_k^*$$

$$+ \frac{1}{2} \sum_t^r \sum_m^r d_{tm} \ln q_t \ln q_m + \sum_j^n \sum_t^r e_{jt} \ln p_j^* \ln q_t \quad (4.40)$$

where the p_j^* are normalized prices, q_t are E/D variables, and the a, b, c, d, and e terms are parameters. With the share equations obtained by taking the partial derivative of ln W with respect to ln p_j^*, the parameters a_0, b_t, and d_{tm} cannot be identified. Note that this occurs because the b_t and d_{tm} terms are price independent. The e_{jt} terms, which are ultimately identified, are price dependent.

In effect, when only the e_{jt} terms are used in the formation of the aggregate price index, there is an implicit assumption that the bt and d_{tm} contributions to the subfunction ln w are zero. In turn, this may restrict the interpretation of the aggregate price index.

One way to incorporate these observations is to estimate the expenditure function of the HTL system as part of a system with the share equations. While this approach would identify the other parameters, it is difficult to implement empirically because the expenditure function depends on the level of indirect utility. Consequently, the aggregate stage demand system for the HTL specification is not estimated.

Estimation of Aggregate Stage Systems

Given the aggregate price indices, it is possible to estimate the LES aggregate stage system. For convenience, it is assumed that the form of the utility function in the aggregate stage is identical to the form of the function used to generate demand curves at the disaggregate stage. Thus, we again look at demand specifications of the LES form.

Table 4-31 presents the final specification for the LES system. As structured, air pollution enters the final stage of analysis only through its effect on the appropriate aggregate price indices. There are seven utility-generating "goods" in the aggregate system, so that six equations are estimated. The parameters A1, B1, C1, D1, E1, and F1 are the marginal budget shares for the services provided by food consumption, shelter, home operations, furnishings, clothing, and transportation, respectively. The marginal budget share for personal care items can be derived from the restriction that the sum of the budget shares must equal unity. These estimates are all statistically significant and appear reasonable in magnitude.

Table 4-32 presents estimates of the own-price demand elasticities for the LES aggregate system. Five of the seven goods have own-price elasticities less than unity, which indicates that as prices decrease, quantity demanded increases less than proportionately so that total expenditure declines. These elasticities are comparable

TABLE 4-31. LES AGGREGATE DEMAND SYSTEM

```
================================================================================

 1:     MFOOD/MTOT = (1-A1)*G1*PFOOD/MTOT+A1-A1*(H1*PSHELTER/MTOT+I1*POFS/MTOT+J1*PHOUSE/MTOT+K1*PCLOTH/MTOT+
        L1*PTRANS/MTOT+N1*PPCARE/MTOT)

 2:     MSHELTER/MTOT = (1-B1)*H1*PSHELTER/MTOT+B1-B1*(G1*PFOOD/MTOT+I1*POFS/MTOT+J1*PHOUSE/MTOT+K1*PCLOTH/
        MTOT+L1*PTRANS/MTOT+N1*PPCARE/MTOT)

 3:     MOFS/MTOT = (1-C1)*I1*POFS/MTOT+C1-C1*(G1*PFOOD/MTOT+H1*PSHELTER/MTOT+J1*PHOUSE/MTOT+K1*PCLOTH/MTOT+
        L1*PTRANS/MTOT+N1*PPCARE/MTOT)

 4:     MOUSE/MTOT = (1-D1)*J1*PHOUSE/MTOT+D1-D1*(G1*PFOOD/MTOT+H1*PSHELTER/MTOT+I1*POFS/MTOT+K1*PCLOTH/MTOT+
        L1*PTRANS/MTOT+N1*PPCARE/MTOT)

 5:     MCLOTH/MTOT = (1-E1)*K1*PCLOTH/MTOT+E1-E1*(G1*PFOOD/MTOT+H1*PSHELTER/MTOT+I1*POFS/MTOT+J1*PHOUSE/MTOT
        +L1*PTRANS/MTOT+N1*PPCARE/MTOT)

 6:     MTRANS/MTOT = (1-F1)*L1*PTRANS/MTOT+F1-F1*(G1*PFOOD/MTOT+H1*PSHELTER/MTOT+I1*POFS/MTOT+J1*PHOUSE/MTOT
        +K1*PCLOTH/MTOT+N1*PPCARE/MTOT)


              CONVERGENCE OBTAINED

              CONVERGENCE ON S OBTAINED


              MODEL: COMMOD2   NOB = 40   NOVAR = 13   NOEQ = 6
              OPT ALGORITHM: DAVIDON-FLETCHER-POWELL
              OPT OPTIONS:  RADIUS = 1.          CONCR = 0.001      ITER LIMIT = 10
              INITIAL S MATRIX:  RESIDUALS CALCULATED FROM INITIAL COEFFICIENT ESTIMATES
              ITERATIVE 3SLS SELECTED:  ITER LIMIT = 15   CONCR = 1.000000E-05
              INITIAL H-INVERSE:  DEFAULT START

               COEF           VALUE          STD ERR          T-STAT

               A1            0.247787        0.025854         9.58423
               B1            0.178237        0.014619        12.1919
               C1            0.013748        0.002516         5.46469
               D1            0.05824         0.018767         3.10336
               E1            0.171044        0.021076         8.11569
               F1            0.212009        0.015769        13.4449
               G1          599.524         108.377            5.53186
               H1          -88.605          57.7975          -1.53302
               J1          107.152          65.9852           1.62387
               K1           84.0169         83.4948           1.00625
               L1           43.3629         43.7388           0.991407
               N1           97.5964         93.5765           1.04296
               I1           48.0724          8.89992          5.40145
================================================================================
```

TABLE 4-32. OWN-PRICE ELASTICITIES OF DEMAND FOR AGGREGATE LES SYSTEM

Category	Elasticity
Food	-0.670
Shelter	-1.110
Home operations	-0.486
Furnishings and equipment	-0.649
Clothing	-1.021
Transportation	-0.929
Personal care	-0.806

to those derived in other studies for similarly defined aggregate categories. For example, Abbott and Ashenfelter (64) report own-price elasticities for a linear expenditure system to be: food (-0.605), housing services (-0.518), durable goods (-1.525), clothing (-0.581), and transportation services (-0.637). Similarly, own-price elasticities for food and clothing are reported by Pollak and Wales (41) to be -0.72 and -0.91, respectively.

Although the food and clothing elasticities from this analysis match up well with those of Pollak and Wales, there are differences between some of this study's elasticity estimates and those reported by Abbott and Ashenfelter. In particular, the housing services and durable goods (furnishings categories) are quite dissimilar. We suspect that much of these differences can be attributed to different definitions of these classes of goods.

CALCULATION OF BENEFITS

Models have been estimated for two structural forms, and measures of air pollution are statistically significant in several of the disaggregate demand systems. In this subsection, this information is used to determine the benefits of attaining the secondary standards. The first task is to describe carefully the scenario for the calculation of benefits. If the benefit numbers are to be useful, the scope of coverage must be made clear. Following the description of the scenario, the concepts presented in Section 2 are developed further. In particular, the notion of an expenditure function is defined and its relation to the compensating variation measure of benefits is noted. With these discussions as background, benefits numbers associated with attainment and maintenance of the Secondary National Ambient Air Quality Standards are presented.

Scenario for Benefits Calculation

There are a variety of scenarios that can be chosen. The particular set of assumptions adopted here is consistent with the timeframe for standard implementation used in a companion study of cost of control and economic impact.

Assumptions for Environmental Variables--

There are three environmental variables in the demand systems estimated in this study. These are the maximum annual second-high readings for SO_2 and TSP, and temperature. The temperature variable included in the benefit calculations is the 30-year annual average for each of the SMSAs in our sample. No change in the annual average temperature is assumed to occur because of air quality improvements.

With respect to the air quality data, the objective is to estimate the incremental benefits of going from a primary standard to a secondary standard. The assumption is that the primary standard is attained in 1985 with the secondary standard being met two years later. Consequently, in order to undertake benefits calculations, it is necessary to describe the air quality levels in 1985. This is done by assuming specific changes in 1978 air quality data, the most recent information available to us. In particular, it is assumed:

- Any SMSA above the primary standard in 1978 would be at the primary standard by 1985.
- Any SMSA below the primary standard in 1978 would remain at the 1978 levels to 1985.

Given attainment of the primary standard, the secondary standard was assumed to be achieved in the following way:

- Any SMSA above the secondary standard in 1985 would reach the secondary standard in 1987 through two equal annual reductions in concentration levels.

- Any SMSA below the secondary standard in 1985 would have no further improvement in air quality.

As an example of the first point, if concentrations of TSP in an SMSA in 1985 are 200 $\mu g/m^3$ and the secondary standard for 24-hour second high (150 $\mu g/m^3$) is to be achieved in two years, this would require a decrease of 25 $\mu g/m^3$ in each year. This assumption requires cities that are further from the secondary standard in 1985 to undertake more intense cleanup efforts if all cities are to be in compliance with the secondary standard by 1987.

The second assumption has implications for the magnitude of gross benefits. This is because it is assumed that cities already in compliance with the secondary standard experience no additional improvements. Thus, there are no benefits accruing to individuals in these cities. This could lead to an underestimate of benefits if, in fact, attainment of the secondary standard leads to a general improvement in air quality for all cities.

Table 4-33 lists the National Ambient Air Quality Standards for TSP and SO_2. The number enclosed in parentheses represents an alternative standard that is not a part of the current Federal regulations but that will also be considered in this study (see Section 3).

TABLE 4-33. NATIONAL AMBIENT AIR QUALITY STANDARDS

Pollutant	Air quality standard ($\mu g/m^3$)	
	Primary	Secondary
Sulfur dioxide		
Annual arithmetic mean	80	--
24-hour maximum*	365	(260)
3-hour maximum*	--	1,300
Particulate matter		
Annual geometric mean	75	--
24-hour maximum*	260	150

* Not to be exceeded more than once per year.

Source: Air Quality Data, Annual Statistics 1977 (65).

Assumptions for Economic Variables--

The crucial assumption with respect to the economic variables is that the parameter estimates derived from 1972-73 data can be used to describe the allocation decisions of individuals in 1985 and beyond. This implies that the structure of individual preferences is not altered by time.

Given the parameter estimates, it is still necessary to describe how the economic variables themselves change over time. The following assumptions were adopted.

- Projections of family income in constant 1972 dollars were obtained for 1985 and 1990 from U.S. Department of Commerce, Regional Economic Projections (66). These data were currently available by state only, but were assumed to be appropriate for our SMSA-level data. The data were converted to 1973 constant dollars, and the annual average percent change between 1985 and 1990 was calculated. This annual percent change was applied to the 1985 data to obtain a measure of family income in 1986 and 1987.

- The projected number of households by SMSA for 1986 and 1987 were derived from state and U.S. projections in the Bureau of the Census, Current Population Reports, Series P-25 (67). The calculated percent change in households between 1986 and 1987 was assumed to hold into the future.

- All benefits calculations were done in constant 1973 dollars. We assumed that there was no intrinsic change in the relative prices of our goods across time. Thus, year-to-year and across-category changes in price were limited to changes in the CPI.

- The benefit numbers are reported in 1980 dollars. The benefit calculations were adjusted to 1980 terms using the annual average percent change in the CPI between 1973 and 1978 as a proxy for CPI changes in any year.

- Benefits are reported as discounted present values in 1980. Three social rates of discount were used: 2, 4, and 10 percent.

- Family size was assumed to remain fixed at 1973 levels throughout the analysis.

The data described above were developed for the 24 SMSAs in the sample. Thus, the benefit numbers legitimately represent only these places. To facilitate comparison with other studies, the scope of coverage has been expanded to develop an estimate of national benefits. These results are reported in Section 10.

Measures of Benefits

In Section 2, the concept of economic benefits was described in general terms. The discussion in that section defined consumers' surplus as the area under a demand curve but above the horizontal price line. Given changes in price, benefits can be measured as the change in consumers' surplus. This situation is shown in Figure 4-7, where an instantaneous price decrease from P_0 to P_1 leads to economic benefits equal to the area P_0ABP_1.

In addition to this standard notion of consumers' surplus, several variations of the consumers' surplus measure have been defined. Given the structure of the model developed in this section, it is convenient to use one of these other measures in the calculation

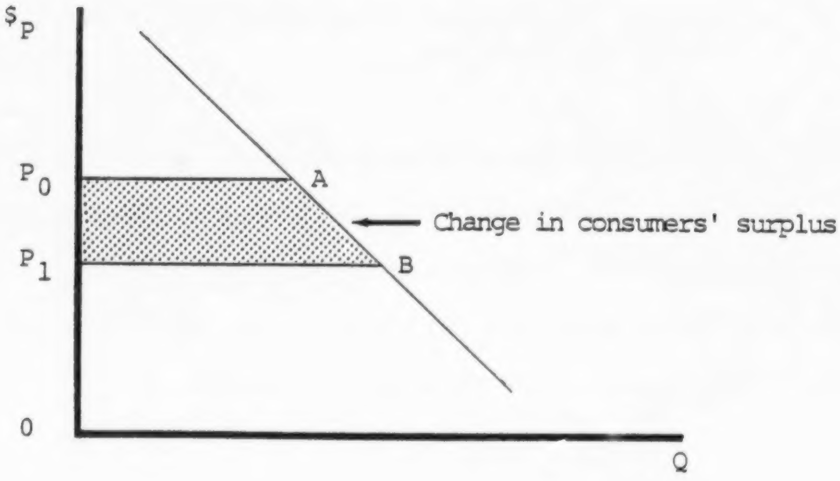

Figure 4-7. Consumers' surplus.

of benefits. In particular, the compensating variation (CV) measure is employed.

As was noted in Section 2, the differences among the various measures of consumers' surplus will be small as long as (1) the magnitude of the measured surplus is small relative to the consumer's income, or (2) the income elasticity of demand for the good or service under consideration is small. These criterion are satisfied for the analysis conducted in this section.

Compensating Variation (CV)--

Compensating variation (CV) can be defined as the amount a consumer would be willing to pay (or would have to be paid) in order to be indifferent between an original situation and a new situation with lower (higher) prices. Figure 4-8 portrays the CV measure in terms of an indifference curve diagram. There are two goods, X_1 and X_2, with X_2 assumed to be a numeraire good which can be thought of as income. Originally, the consumer faces relative prices shown by P_0P_1. He maximizes utility along U_1 at point A. If the price of X_1 falls due to an improvement in air quality, the new price line is given by P_0P_2. With this lower price for good X_1, the consumer achieves a higher level of utility (U_2), and maximizes utility at point B in the diagram. For a price decrease, CV measures the amount the consumer would be willing to pay to attain the original level of utility (U_1) at the new set of prices. Thus, if the amount P_0D in income is taken away from the individual and he is faced with the same relative prices

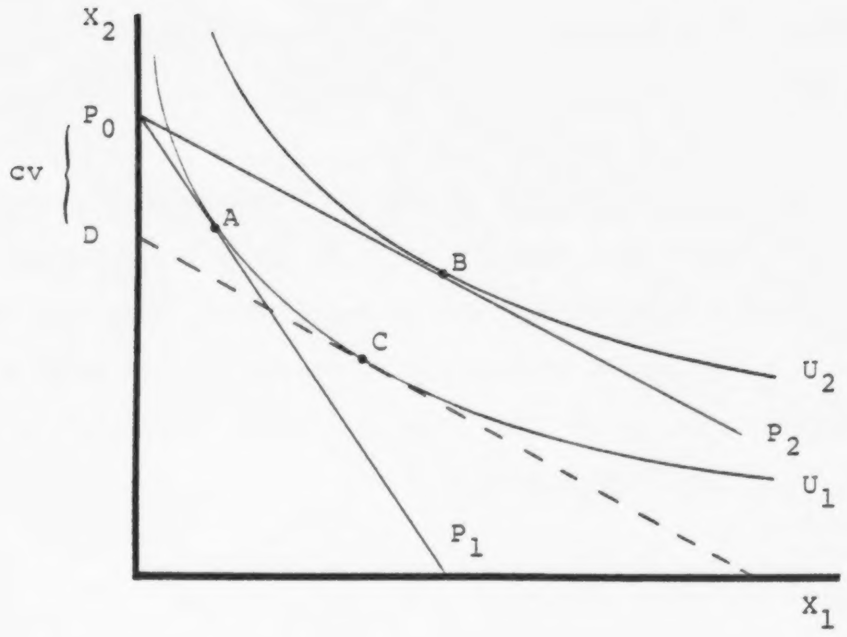

Figure 4-8. Compensating variation.

as after the price change, he could consume combination C of goods X_1 and X_2 and be on U_1. P_0D is the measure of CV for the given price change. This is the measure used in reporting the benefits numbers.*

The Expenditure Function--

The CV measure of welfare change can be made operational with the concept of an expenditure function. This function shows the minimum dollar expenditure required to reach a specific level of utility, $\overline{U}$, given prices P. It can be obtained through solution of the mathematical dual to the consumer's utility maximization problem. That is, it is a solution to a decision problem in which the consumer is assumed to minimize expenditures subject to a constant level of utility.

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* For a comparison of CV and other measures of benefits, see Freeman (7).

With this definition of an expenditure function, CV can be defined as the difference between an expenditure function evaluated before and after a price change, such that utility remains constant.

$$CV = E(P^1,\overline{U}) - E(P^2,\overline{U}) \tag{4.38}$$

where P^1 is a vector of prices in an initial situation and P^2 is a vector of prices after a price change. If $CV < 0$, then the consumer must be compensated and if $CV > 0$, the consumer should be willing to pay the amount CV if he is to be at the same level of utility as before the change.

The benefits estimates reported below are derived from Equation (4.38). This requires knowledge of the expenditure function before and after the postulated change in air quality. The expenditure function is defined by solving analytically for the compensated demand curves associated with the Linear Expenditure System. Since the structural parameters of the ordinary demand equations presented earlier can be identified on a one-to-one basis with the parameters of the compensated demand equations, there is no need for additional estimation. Note also, that the indirect utility function of the

Linear Expenditure System can be used to determine the constant level of utility appearing in the expenditure functions.

Economic Benefits of Air Quality Improvements

Table 4-34 presents the benefit estimates derived from the series of demand specifications presented earlier in this section. Results are reported separately for TSP and SO_2, and regional subtotals are given. The benefits are reported as discounted present values in 1980, in millions of 1980 dollars. The estimates shown are for a 10 percent discount rate.

An important assumption implicit in the calculation of these benefits is that both pollutants are expressed in terms of maximum annual 24-hour second-high concentrations. While these units are appropriate for the air quality standards defined for TSP, no such secondary standard is currently part of the Federal regulations for SO_2. The only current SO_2 secondary standard is based on a 3-hour averaging time. In Section 3, assumptions were presented that would be required to determine the 24-hour second-high concentration that would be expected to occur when the 3-hour concentration of 1,300 $\mu g/m^3$ occurred once per year (i.e., the secondary standard is attained). This concentration level was termed the 24-hour equivalent standard. If the appropriate transformations are made and all primary standards are assumed to be met, none of the 24 SMSAs are found to be out of compliance with the 24-hour SO_2 equivalent secondary standard.

TABLE 4-34. HOUSEHOLD SOILING AND MATERIALS DAMAGE BENEFIT ESTIMATES (discounted present values for 1980 in millions of 1980 dollars)

SMSAs	TSP	SO_2
Region I		
Boston	35.41	*
Buffalo	47.98	37.99
New York	237.05	302.75
Philadelphia	189.71	184.45
Pittsburgh	83.35	74.67
Region Subtotal	593.50	599.86
Region II		
Chicago	254.11	65.45
Cincinnati	21.34	39.88
Cleveland	61.59	52.20
Detroit	172.88	*
Kansas City	39.08	*
Milwaukee	51.92	36.84
Minneapolis	73.95	56.26
St. Louis	85.92	70.06
Region Subtotal	760.79	320.69
Region III		
Atlanta	4.67	*
Baltimore	7.47	*
Dallas	56.00	*
Houston	105.79	*
Washington, DC	152.23	*
Region Subtotal	326.16	*
Region IV		
Denver	112.32	*
Honolulu	*	*
Los Angeles	367.73	*
San Diego	86.61	*
San Francisco	*	*
Seattle	53.48	*
Region Subtotal	620.14	*
Totals	2,300.59	920.55

* Secondary standard not exceeded; therefore no benefits for attainment of standard.

As noted in Section 3, this result is not too surprising since the 3-hour standard is expected to be the "controlling" standard only in areas with extremely high, strong sources of SO_2. Furthermore, given that the damages analyzed here (soiling and materials damage) are likely to be more sensitive to longer averaging times, it appeared reasonable to estimate benefits for an alternative 24-hour secondary standard such as the 260 $\mu g/m^3$ value listed in Table 4-33. The benefits shown in Table 4-34 are for this alternative SO_2 standard.

Total benefits for the 24 SMSAs, with a 10 percent rate of discount, are \$920 million and \$2.30 billion for SO_2 and TSP, respectively. With a social rate of discount of 4 percent, benefits increase to \$3 billion for SO_2 and \$7.97 billion for TSP. A further reduction in the social rate of discount to 2 percent leads to benefit estimates of \$5.17 billion for SO_2 and \$14.1 billion for TSP.

On a regional basis, TSP benefits are realized throughout the nation, while SO_2 benefits accrue to households only in the Northeast and North Central parts of the country.

The aggregate benefit estimates in Table 4-34 can also be broken down on a per-household basis. For example, in the two years of standard attainment, the average per-household benefits are about \$16.25 and \$16.50 for TSP and SO_2, respectively. Furthermore, for a unit change in air pollution ($\mu g/m^3$), the per-household benefits average about \$0.20 and \$0.17 for TSP and SO_2. These numbers can be interpreted as an indication that the average family in the 24 SMSAs in this study should be willing to pay $0.37 for a simultaneous one-unit reduction in ambient concentrations of TSP and SO_2.

These benefit numbers represent our "most reasonable" estimates of the air quality benefits that would be realized in the household sector, for the 24 SMSAs, with attainment of the 24-hour maximum second-high secondary standards. In the remaining parts of this subsection, these estimates are compared to those derived via other models and approaches.

Comparison With Property Value Estimates--

In the organizational stages of this project, an area of concern was to identify alternative ways of checking the plausibility of the benefits numbers derived in the household expenditure model. Among the options considered was to make a comparison with other indirect-market studies such as the property value models.

These studies were considered appropriate as plausibility checks since soiling and materials damage benefits are among the benefits covered by the property value analyses. In addition to coverage of soiling and materials damage, the property value studies are generally considered to include health and at-home aesthetic benefits as well. Unfortunately, it is not possible to identify the separate influences of the various types of benefits. Consequently, benefits obtained from a study of property value differentials should provide an upper-bound plausibility check on the benefits derived in this section.

With this in mind, a review of property value studies was undertaken. The results of this review are presented in Section 5. In developing the benefits estimates in Section 5, assumptions were adopted which were consistent with the assumptions used in calculating benefits in this section. A strict comparison of the benefits estimated using the two approaches is not possible, however, since the property value studies reviewed in Section 5 generally use the annual mean of TSP and SO_2. Consequently, the benefits reported in Section 5 are based on an alternative secondary standard of an annual mean of 60 $\mu g/m^3$ for both TSP and SO_2. Since the current secondary standard used to calculate benefits in the household expenditure model is likely to be more stringent than the alternative secondary standards used in Section 5, the benefits reported from the household expenditure model may exceed those reported from the review of the property value studies. On the other hand, the property value benefits are likely to exceed the benefits estimated from the household expenditure model, since the property value benefits include health and at-home aesthetic benefits. Table 4-35 presents a comparison of the benefits obtained with the two approaches. As shown in the table, the sum of the benefits estimated from the household expenditure model fall within the range of the sum of benefits estimated from the property value studies. Without additional supporting evidence on the stringency of the current secondary standard in relation to the alternative

TABLE 4-35. COMPARISON OF THE BENEFITS IN THE HOUSEHOLD EXPENDITURE MODEL AND THE PROPERTY VALUE MODEL (discounted present values for 1980 in billions of 1980 dollars)

Pollutant/ Standard	Household expenditure model	Property value differentials
TSP	2.3	2.08 - 4.99
SO_2	0.92	0.33 - 0.47

secondary standard used in the property value analysis and the likely magnitude of aesthetic or health benefits in the SMSAs considered in this analysis, it is difficult to judge the reasonableness of the relative benefit levels shown in Table 4-35.

Comparison With Wage Rate Estimates--

A second plausibility check for the household model can be obtained by analysis of the market for labor services. As with the property value studies, benefits derived via a wage model cover a variety of benefit types. In addition to soiling and materials damage benefits, the wage models include benefits for health and aesthetic effects. Again, since the separate influences of the health and aesthetic effects cannot be isolated, benefits obtained from a study of wage rate variations should provide an upper-bound check on the benefits derived in this section.

Section 6 outlines the basic structure of the (hedonic) wage analysis, and derives benefits estimates for two of the SMSAs included in the household sector analysis. A comparison of the results between the wage and household models is presented in Table 4-36. Note that the benefits estimates are reported on a per-household basis. This is the appropriate comparison since the wage analysis excludes self-employed and part-year workers. Thus, a simple comparison across total population for an SMSA is not possible.

Like the property value analysis, the benefits estimated from the wage rate study are based on an alternative secondary standard of 60 $\mu g/m^3$ annual mean of TSP. In addition, the wage study benefits include health and aesthetic benefits. Therefore, a strict comparison of these estimates is not possible without additional information on these factors.

TABLE 4-36. COMPARISON OF THE PER-HOUSEHOLD BENEFITS OF ATTAINING SECONDARY STANDARDS FOR TSP (1980 $)*

SMSA	Household expenditure model	Hedonic wage model
Cleveland	6.23	189.40
Denver	7.39	212.40

* 1980 discounted present value of the per-household benefits occurring in 1987.

Comparisons With Damage Function Studies--

In an earlier subsection, three studies were mentioned that provided an assessment of national benefits for reductions in TSP and SO_2 [(1), (4), (18)]. In each of these studies, benefits estimates were developed by using damage relationships from earlier, independent studies. In fact, many of the damage relationships used are the same across the three studies. The differences that occur in reported benefits come about because of differences in the assumptions used to calculate benefits. These differences also make it difficult to compare benefits from the damage function studies with those developed in this section.

One of the few results that appears to be amenable to comparison with our results is the soiling damage estimates reported by Freeman (4). Using a model developed by Watson and Jaksch (15), Freeman concludes that the best estimate associated with achievement of the secondary standard for TSP (annual mean) is $2.0 billion annually. This number is expressed in 1978 dollars and covers 122 SMSAs. The annualized estimate for our discounted present value of TSP benefits (24-hour second high), in 1980 dollars, is approximately $0.23 billion for 24 large SMSAs.

While it is a straightforward calculation to convert our dollar figures to 1978 terms, more detailed procedures are necessary for geographic extrapolation. However, no extrapolations are undertaken in this section. Extrapolation issues are addressed in Section 10 where a summary is provided of the level of national benefits for the household model.

Despite the intrinsic differences among the various damage function studies that have been discussed and the present effort, it may be possible to make rough comparisons by attempting to replicate the air quality scenario used by one of the other studies. For example, one of the differences pointed out between the current study and that conducted by SRI (18) was that SRI's benefits estimates were calculated from current (1980) levels to the secondary standard rather than from the primary standard to the secondary standard. If this difference is removed, it would be possible to make a rough comparison of the benefit estimates.

Note that even with this change, there are still several important differences between the two studies which make comparisons difficult. These include:

- Our "current" year for benefits calculations is 1978. SRI's is 1980.
- The maximum annual 24-hour second high is used in this study as the pollution measurement index. SRI uses an annual mean.
- The geographic scope in this study covers 24 SMSAs. SRI reports national benefits estimates.
- This study focuses on the household sector. SRI does not make this distinction.
- In this study, the secondary standard is assumed to be achieved in the two years 1986-87. SRI appears to assume instantaneous attainment in 1980.

- The benefit numbers reported in this study are discounted present values. SRI appears to report an annualized number.

Only the last point is relatively easy to address. In Table 4-37, discounted present values are presented for the scenario described above. The SRI estimates were reformulated as discounted present values by assuming an infinite horizon for benefits and a 10 percent social rate of discount. As would be expected from the various differences that remain in the two studies, the SRI estimates are larger than those reported for the household sector. As with the property value comparisons, it is difficult to make further judgments about the reasonableness of the relative magnitudes.

One point that is brought out by Table 4-37 is that there are welfare benefits to be gained by attainment of the primary standard. In particular, a comparison of Tables 4-37 and 4-34 reveals that additional benefits of \$3.08 billion for TSP and \$1.14 billion for SO_2

TABLE 4-37. COMPARISON BETWEEN SRI BENEFIT NUMBERS AND THE PRESENT STUDY (discounted present values for 1980 in billions of 1980 dollars)

	TSP	SO_2
SRI estimates	6.50	18.00
Current study estimates	5.38	2.06

are realized with primary standard attainment.* These welfare benefits should not be neglected in an analysis of the benefits associated with attainment of the primary standard.

Sensitivity of Results to Alternative Assumptions--

The benefit estimates presented in Table 4-34 are reported as point estimates. Given the stochastic nature of the equations that have been estimated, it is perhaps more realistic to think in terms of a range of benefits estimates.

With this in mind, an ad hoc check based on the statistical properties of the estimated coefficients in the demand equations was undertaken. The check devised involves perturbing the estimated coefficients of the air quality variables by a given amount. For example, the estimated coefficient for TSP in the home operations subsystem of the LES specification was found to be 0.01865. This is the point estimate used in constructing the aggregate price index. However, this coefficient is a random variable with a standard deviation of 0.00647. Thus, the coefficient can take on a range of values. A question of interest might be, how do the benefit estimates change if the coefficients of all the pollution variables are assumed to take on values plus and minus one standard deviation from the mean value? While covariances among variables make such a test nonrigorous, the results can still be informative.

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* These are rough estimates since they do not take into account that the primary standard is to be achieved in 1985.

Tables 4-38 and 4-39 present the low, "most reasonable", and high estimates for benefits when these changes are made. Table 4-38 reports the results for SO_2, while Table 4-39 describes the range of TSP benefits. As earlier, these numbers are discounted present values in 1980, in millions of 1980 dollars. The social rate of discount is assumed to be 10 percent. Again, note that these benefit estimates are only for the 24 SMSAs included in the basic household analysis.

SUMMARY OF HOUSEHOLD SECTOR

In this section, economic benefits of achieving secondary air quality standards for TSP and SO_2 in 24 SMSAs have been estimated. The "most reasonable" estimate of the benefits associated with attainment of the SO_2 standard is about $920 million, while the benefits realized with attainment of the TSP secondary standard are about $2.3 billion. These benefit estimates are discounted present values in 1980, in 1980 dollars. A 10 percent social rate of discount is assumed.

The approach used to obtain these estimates is different from approaches used in previous air quality benefits studies. In the present analysis, considerable attention has been given to developing estimates which: 1) are consistent with the theoretical definition of benefits, 2) account for household adjustments to air pollution, 3) are derived from a well-tested model, 4) are based on real world data, and 5) are plausible in comparison with estimates using other

TABLE 4-38. RANGE OF HOUSEHOLD SECTOR BENEFITS FOR SO_2 (discounted present values for 1980 in millions of 1980 dollars)

Region	Low	Most reasonable	High
Northeast	$356.67	$599.86	$ 839.73
North Central	191.34	320.69	448.33
South	*	*	*
West	*	*	*
Total benefits	$548.01	$920.55	$1,288.06

* Secondary Standard not violated for SMSAs included in analysis.

TABLE 4-39. RANGE OF HOUSEHOLD SECTOR BENEFITS FOR TSP (discounted present values for 1980 in millions of 1980 dollars)

Region	Low	Most reasonable	High
Northeast	$ 332.91	$ 593.50	$ 855.67
North Central	430.42	760.79	1,095.26
South	184.77	326.16	468.86
West	350.97	620.14	893.62
Total benefits	$1,299.07	$2,300.59	$3,313.41

techniques. The inclusion of each of these features in a single study represents an important contribution to air quality benefits analysis.

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SECTION 5

RESIDENTIAL PROPERTY MARKET

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RESIDENTIAL PROPERTY MARKET

INTRODUCTION

Section 4 of this report uses an economic model of household expenditure decisions to estimate some of the benefits that would result from attainment of the secondary national ambient air quality standards for TSP and SO_2. The benefits estimated by that model primarily reflect reduced soiling and materials damage within the household sector. Not included in those estimates are benefits arising in other sectors (e.g., agricultural benefits), or other household sector benefits such as improved visibility.

Many previous studies have developed estimates of household sector benefits by analyzing differences in residential property values. The underlying hypothesis in those studies is that residential property values will reflect not only housing quality but also site-specific attributes such as location, neighborhood characteristics, availability of services, and environmental quality including air quality.

The purpose of this section is to draw upon the results of representative property value studies to provide a cross-check on the magnitude of the benefits estimated by the household expenditure model. As discussed previously in Section 2, one would expect the estimates based on property values to be larger than the estimates from the household expenditure model. This is because the former will tend to include a broader range of effects such as visibility benefits and possibly some health benefits. Thus, by comparing the estimates from these two methodological approaches applied to the same geographic areas, one can assess whether the household expenditure model estimates are consistent (i.e., smaller in magnitude) with the estimates based on property values.

Using the same air quality data employed in Section 4, the property value technique is used in this section to develop benefits estimates for the same 24 SMSAs (metropolitan areas) examined in Section 4. Benefits are estimated for the same air quality scenarios -- attainments of alternative secondary ambient air quality standards for TSP and SO_2. The resulting estimates from the two methods are compared in Table 5-1. As can be seen in the table, a reduction in the ambient level of TSP within each of the 24 SMSAs has been estimated to result in a discounted present value of benefits in 1980 dollars in the range of \$2.08 to \$4.99 billion.* A reduction in the ambient level of SO_2 within each of these SMSAs are estimated to result in benefits in the range of \$0.33 to \$0.47 billion in 1980 dollars.* As Table 5-1 shows, the sum of the estimates from the

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* Using a 10 percent rate of discount.

TABLE 5-1. COMPARISON OF THE BENEFITS FROM ATTAINING ALTERNATIVE SECONDARY STANDARDS IN 24 SMSAs (billion $)

Pollutant/ standard	Property value differentials	Household expenditure model
TSP	2.08 - 4.99	2.3
SO_2	0.33 - 0.47	0.92

household expenditure model fall within the range of the sum of benefits estimated from the property value studies.

In addition, the benefits estimated in this section should be considered to be general approximations of the benefits resulting from the attainment of alternative secondary standards in these 24 SMSAs for the following reasons: 1) The results of studies on specific cities in the early 1960's and 1970's are used to estimate the benefits of pollution reductions occurring in 1986 and 1987 for the 24 SMSAs. If the valuation of air quality improvements has changed significantly since that time, the use of these study results can only be considered as approximations of the benefits of attaining alternative secondary standards. 2) These estimates are based on studies that generally examine the relationship between residential property values and the annual average, as opposed to the second highest, pollution readings. 3) The maximum of the second highest pollution reading within an SMSA is taken as representative of the level of exposure of all households within the SMSA. 4) The marginal willingness to pay for air quality improvements of households residing in single-family units is assumed to be representative of all households.

General Background

The analysis of residential property value differentials has been widely used for estimating the benefits of reductions in air pollution levels. This method assumes that the benefits of living in a clean air environment are capitalized into property values. In other words, what people are willing to pay for air quality improvements can be measured by the observed differences in the value of residential properties that are identical in every respect except air pollution exposure.

Since this method focuses on the decisions made in the housing market, the household does not need to know the technical relationship between air pollution and physical damage. The household, however, must be able to perceive the effect of different levels of air quality, and make decisions in the housing market based on that perception. Consequently, the types of benefits that are measured through the property value method are any perceived health, physical property, aesthetic, or psychic benefits that are the result of residing in an area with relatively clean air. Because some of the effects of air pollution are probably not perceived by households, one of the disadvantages of property value studies is that they cannot provide estimates of all the benefits that result from air quality improvements. For example, health effects that are not perceived by the household will not be captured by residential property values. Another disadvantage is that residential property value studies may only provide estimates of benefits that occur at home. For example, benefits of air quality improvements that occur at recreation areas and the workplace may not be measured by residential property value differentials.*

One of the major advantages of property value differential analysis is the ability to capture the value that households place on the aesthetic and psychic amenities of the place where they reside. Neither health studies nor dose-response functions measure the aesthetic benefits of improvements in air quality. In addition, property value studies can reflect the choice of substitute activities and goods that are used as a means of offsetting the effects of pollution. If the members of a household substitute indoor activities for outdoor activities on certain days because of poor air quality, this reduced flow of services from the property would be reflected in a lower property value. It is possible, however, that the purchase of goods to offset the effect of pollution may result in an enhancement of the property value in a polluted area. If central air conditioning, for example, is bought by a household in order to offset the effects of pollution, the value of that house is higher relative to an identical home without air conditioning that is exposed to the same level of pollution. This can be correctly reflected in property value differentials if air conditioning is identified as one of the attributes of housing.

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* It is possible that property values, in addition to reflecting the value individuals place on amenities at the home, may also reflect the value placed on amenities at the workplace since once an individual makes a residential location decision, the choice of other locational amenities, such as those at the worksite, are limited. See Cropper (1).

Since the purpose of this study is to measure the welfare benefits of attaining proposed alternative secondary standards, we have assumed that the primary standards have been met. Although the primary standard was established to protect human health, there is the possibility that some health benefits may remain to be captured when moving from the primary to secondary standard. On the other hand, some part of the physical property and aesthetic benefits of a cleaner environment will be captured in achieving the primary standard. Consequently, the benefits estimated in this section by the analysis of residential property value differentials will be limited to the perceived at-home health, physical property, and aesthetic benefits of the reductions in air pollution from the primary to alternative secondary standards.*

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* The majority of property value studies have estimated air pollution control benefits based on reductions in pollution over a range that would most likely include the majority of perceived health benefits. The appropriateness of using the results of these studies to estimate the benefits of moving from the primary to secondary standards is addressed in the Benefit Estimates subsection.

As mentioned in Section 4, the household expenditure model, as currently developed, provides estimates of only the short-run benefits accruing to the household that result from a change in air quality. Since the model does not at the present time reflect the long-run adjustments to changes in air quality, the changes in property value that result from changes in air quality are not measured. It must be mentioned, however, that it is not appropriate to add the benefits estimated by the consumer budgeting model to the benefits that will be estimated in this section because there certainly will be some overlapping of the benefits estimated by these two models. For example, an improvement in air quality that results in a reduction in expenditures on home repairs probably will be reflected in an increase in the value of the property.

Methodology

The use of property value differentials as a means of determining the willingness to pay for air quality improvements has its underpinnings in the hedonic price technique. This technique was originally developed by L. M. Court (2). Griliches and Adelman (3), Griliches (4), Ohta and Griliches (5), Kain and Quigley (6), and others have used the technique to estimate the value of changes in the quality of consumer goods. Generally stated, the hedonic technique examines the functional relationship between the price of a good and its characteristics.* It has been used extensively as a means of estimating the marginal willingness to pay for environmental quality [Harrison-Rubinfeld (7); Nelson (8)]. In these studies, housing values are regressed on a set of housing characteristics which includes a measure of air quality.

Before explaining the hedonic technique, it is necessary to address the question of whether predicted changes in property values are accurate measures of the total benefits of air quality improvements. Using a model of locational choice, Polinsky and Shavell (9) have shown that predicted property value changes are accurate measures of these benefits only under certain rather stringent assumptions. Their explanation proceeds as follows:

Assume that there is a city inhabited by individuals with identical utility functions and equal incomes.* People work in the center of the city and reside in the area surrounding the center city. Air quality (AQ) at a specific location increases with distance (d) from the center city. Travel cost (T) to the center city is also an increasing function of d. Utility in this city is a function of the consumption of household services (H), a composite good (X), and the level of air quality [AQ(d)]:

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* See Chapter 1 of Griliches (4) for a summary of the hedonic price technique.

** The model can be generalized to reflect the possibility that there is more than one utility function and unequal incomes within the city. In this case, there would be i consumer groups ($i = 1,n$) where each member of the i^{th} group would have identical utility functions and incomes. This would only serve to complicate the analysis without changing the results. If incomes are endogenous to the model, however, the following results will be altered.

$$U = U\ H,\ X,\ AQ(d) \qquad (5.1)$$

The consumer desires to maximize his utility subject to the budget constraint:

$$Y = p(d)H + X + T(d) \qquad (5.2)$$

where Y = money income,

$p(d)$ = per unit price of housing services at a location with distance (d) from the center city,

H = household services,

X = the composite good with price equal to 1, and

$T(d)$ = commuting costs to the center city.

By solving the first-order conditions of the utility maximization problem, Equation (5.1) can be stated in terms of an indirect utility function -- utility as a function of the demand functions for H, X, and AQ:

$$U = I[p(d),\ Y-T(d),\ AQ(d)] \qquad (5.3)$$

Under the assumption of unrestrained and costless mobility throughout the city, and identical utility functions and income, a common equilibrium level of utility, U^*, will be obtained. At U^*, no individual can increase his utility level by moving.

$$U^* = I[p(d), Y-T(d), AQ(d)] \tag{5.4}$$

Implicit in this relation is the equilibrium housing function:

$$p(d) = P[U^*, Y-T(d), AQ(d)]. \tag{5.5}$$

It is important to note that the equilibrium price of housing is a function of U^* as well as Y-T(d) and AQ(d).

In Polinsky and Shavell's paper, Equation (5.5) is used to explain the conditions under which a new property value schedule can be predicted from a change in air quality. If it is assumed that the city is small and there is perfect and costless mobility among cities, then U^* will be the same across all cities and exogenous to the small city. If air quality improves within the small city, U^* will not change and the change in property value is only dependent on the characteristics of d. A regression equation specifying the relationship between p(d) and d can be used in this case to predict the change in property values resulting from a given change in air quality. If the city is either large, or there is imperfect mobility among cities, then U will be endogenous. If air quality improves within the city, U will be affected. In this case, the new property value schedule cannot be predicted without first using a general equilibrium model to determine the new level of U resulting from the change in air quality.

In general, therefore, property value equations that predict the change in property value for a given change in air quality can be used to estimate the willingness to pay for air quality improvements only if the following assumptions are met:

- The geographical area under consideration must be small.
- There must be perfect mobility throughout, and into and out of, the geographical area.
- There must be no changes in input and output prices.

The hedonic technique, however, does not attempt to predict a new property value schedule resulting from a change in air quality, but rather estimates the marginal willingness to pay for air quality improvements by observing the housing market in equilibrium. In this method, the implicit price of air quality is identified by examining the differentiated prices within the housing market that result from variations in existing air quality. Since the housing market is in equilibrium, the implicit price of air quality can be shown to be equal to the marginal willingness to pay for air quality. The hedonic technique is therefore useful in predicting the benefits of marginal changes in air pollution. Given certain conditions, the implicit prices estimated by the hedonic technique and other relevant variables can be used to estimate the inverse demand function for air quality.

Through the estimation of this demand curve, the benefits of non-marginal changes in air quality can also be predicted.

The general form of a hedonic equation relates the price of a good to the characteristics of that good. As applied to the housing market, this can be expressed as:

$$R_i = r(S_i, N_i, Q_i) \tag{5.6}$$

where R_i = price of the i^{th} residential location.

S_i = a vector of structural characteristics of the i^{th} location.

N_i = a vector of neighborhood characteristics of the i^{th} location.

Q_i = a vector of environmental characteristics of the i^{th} location with one element in the vector being air quality (q_1).

Note that housing price in the hedonic equation is a function only of the characteristics of the house, not of the household.

The assumptions that are necessary in order for the hedonic equation to estimate the marginal willingness to pay for air quality improvements are:

- The housing market must be in equilibrium.
- Individuals must be able to perceive the characteristics and attributes of housing.

- A complete range of houses with alternative characteristics must be available.

The partial derivatives of property value with respect to the housing characteristics are interpreted as the marginal implicit prices or the additional amount that must be paid for a house with one more "unit" of a particular characteristic, ceteris paribus. Since one of the assumptions of the property value model is that the housing market is in equilibrium, the marginal implicit price is therefore equal to the marginal willingness to pay for that characteristic. In terms of the partial derivative of property value with respect to air quality ($\partial R_i/\partial q_1$), an estimate of the equilibrium willingness to pay for marginal air quality improvements is obtained.

In order to see why the partial derivatives of the housing equation variables are equal to the equilibrium marginal willingness to pay for housing characteristics, it is helpful to develop a model of consumer choice following Rosen (10).*

Let's assume that there is a consumer whose utility is dependent on the consumption of a composite good (X) and a vector of housing characteristics (H) where air quality (h_1) is an element in the vector:

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* Rosen's paper dealt with both the consumption and production of a good that could be defined in terms of its attributes and characteristics. Since the hedonic price technique only reveals the equilibrium outcome of demand and supply conditions and not the underlying demand and supply functions, and since the purpose of this paper is to estimate the willingness to pay for air quality improvements, we will limit our discussion to the consumer allocative decisions made for housing.

$$U = U(X, h_1, \dots, h_n) \qquad (5.7)$$

The consumer has income (y) which can be expressed as:

$$y = X + p(H) \qquad (5.8)$$

where $p(H)$ = price of housing.
X = the composite good with price equal to 1.

Setting up the Lagrangian, the consumer maximizes U subject to his budget constraint. The first order conditions can be expressed as:

$$\partial U/\partial X = \lambda \quad \text{and} \quad \partial U/\partial h_i = \lambda \partial p(H)/\partial h_i \qquad (5.9)$$

where λ = the Lagrangian multiplier.

By combining equations, we find that in equilibrium the marginal rate of substitution between each housing characteristic and the composite good is equal to the partial derivative of the price of housing with respect to that particular characteristic (i.e., the implicit price of the characteristic estimated by the housing equation):

$$(\partial U/\partial h_i)/(\partial U/\partial X) = (\partial p(H)/\partial h_i) \quad . \tag{5.10}$$

If X is thought of as money (the price of a dollar is equal to $1.00), equilibrium is achieved when the marginal rate of substitution between h_i and money is equal to the marginal implicit price of h_i. Since the marginal rate of substitution between h_i and money can also be viewed as the marginal payment for h_i with money, the equilibrium conditions can be expressed as equating the marginal willingness to pay for h_i (with money) with its marginal implicit price.

The equating of the marginal implicit price and the marginal willingness to pay can also be explained by viewing equilibrium in terms of a particular h_i. Assume that there is a level of consumer utility, u, that can be defined by the function:

$$U(y - \Theta; h_1, \ldots, h_n) = u \tag{5.11}$$

where $y - \Theta = X$.

For a given u, Equation (5.11) can be thought of as an indifference curve relating the tradeoff between h_i and X. A bid function:

$$\Theta(h_1, \ldots, h_n; u, y) \tag{5.12}$$

can be derived from Equation (5.11) which relates the alternative expenditures a consumer is willing to make for h_i given a certain level of utility and income. By totally differentiating (5.11), we find that:

$$\partial U/\partial X\ (dy - d\theta) + \partial U/\partial h_1\ dh_1 + \ldots + \partial U/\partial h_n\ dh_n = du \qquad (5.13)$$

Given the assumption of a fixed level of utility and income, $du = 0$ and $dy = 0$. If $dh_k = 0$ for $k \neq i$, Equation (5.13) reduces to:

$$\partial\theta/\partial h_i = (\partial U/\partial h_i)/(\partial U/\partial X) \quad . \qquad (5.14)$$

Viewing a particular h_i, h_1 as air quality, Equation (5.14) shows that the marginal rate of substitution between air quality and X (money) is equal to the marginal implicit bid for air quality ($\partial\theta/\partial h_1$) at a given level of utility and income.

Figure 5-1 shows the bid function of consumer j for air quality while holding everything else constant, $\theta^j(h_1, h_2^*, \ldots, h_n^*; u^*, y^*)$. There are a number of different bid functions reflecting the different levels of tastes, preferences, and income of consumers. This function shows the willingness to pay (bid) for air quality in terms of the amount of money (X) foregone, ceteris paribus. The minimum implicit prices revealed in the market that must be paid for different levels of air quality while holding h_2 through h_n constant is shown by $p(h_1, h_2^*, \ldots, h_n^*)$. Equilibrium is reached when $\theta^j(h_1, h_2^*, \ldots, h_n^*; u^*, y^*)$ is tangent to $p(h_1, h_2^*, \ldots, h_n^*)$; i.e., where the marginal

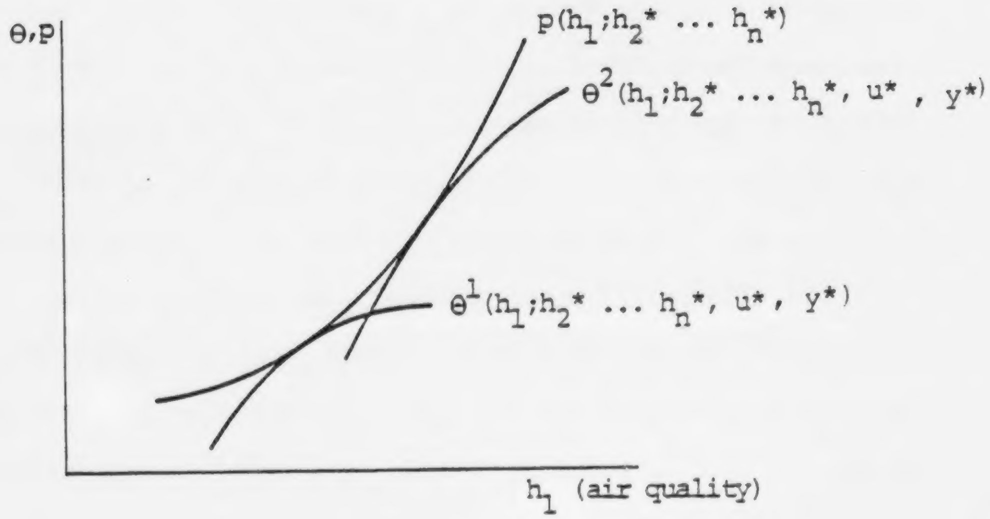

Figure 5-1. Implicit price schedule and bid functions.

willingness to pay for air quality is equal to its marginal implicit price.

Since the hedonic equation can be expressed by $p(h_1, \ldots, h_n)$, the marginal implicit price schedule for air quality ($\partial p(H)/\partial h_1$) can be easily obtained by taking the derivative of the hedonic housing equation with respect to air quality (see Figure 5-2). Assuming that the housing market is in equilibrium and following the above explanation, this schedule will also trace out the loci of marginal willingness to pay equilibria for different levels of air quality by consumers with different bid functions. Note that unless all consumers have identical bid functions (i.e., identical utility functions and incomes), the hedonic technique yields only the equilibrium marginal willingness to pay of consumer j with bid function θ^j. This is only one point on consumer j's demand price function for h_1 while holding utility constant (i.e., the inverse compensated demand function). Consequently, $\partial p(H)/\partial h_1$ is not the inverse compensated demand function for air quality and, in most cases, can only be used to compute the benefits of marginal improvements in air quality. In order to accurately estimate the demand curve for air quality and predict the benefits of non-marginal changes in air quality when consumers do not have identical utility functions and incomes, additional information and steps are needed.

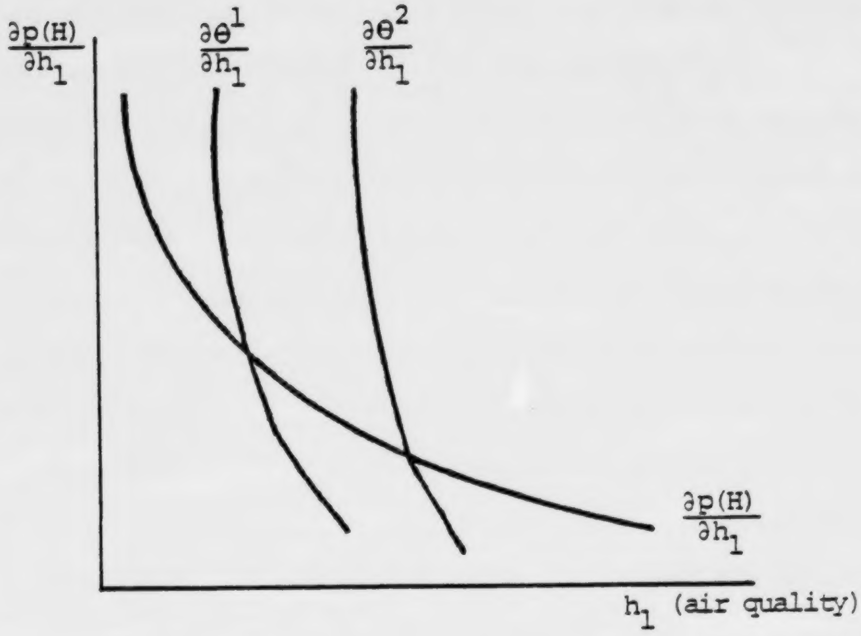

Figure 5-2. Marginal implicit price schedule and demand price functions.

Literature Review

The first study undertaken to measure the relationship between property values and the level of air quality was done by Ridker and Henning (11). Using 1960 cross-sectional census tract data from the St. Louis metropolitan area, the effect of air pollution levels on property values was estimated using regression analysis. The dependent variable was the median value (estimated by owner) of owner-occupied single-family housing units, and the independent variables included those reflecting location characteristics (e.g., accessibility to highway, travel time to central business district), property characteristics (e.g., median number of rooms, houses per mile), neighborhood characteristics (e.g., school quality, persons per housing unit), median family income, and an air pollution variable (an index indicating the presence of SO_2, SO_3, H_2S, H_2SO_4, and in some cases dustfall). Different linear specifications were tried and a significant negative relationship was found between the dependent variable and the air pollution variable. From these results, they concluded that property values could be expected to rise at least \$83.00 and more probably \$245, if the measurement of SO_3 were to drop by 0.25 $\mu g/100\ cm^2/day$.*

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* Freeman (12) concluded that Ridker and Henning's results were over-interpreted and could not be used to predict changes in property values when air quality changed because the demand curve for air quality had not been identified. This led to quite a debate in the literature over the proper interpretation of the derivative of the air quality variables. [See Anderson and Crocker (13); Freeman (14); Polinsky and Rubinfeld (15); Small (16); and Harrison and Rubinfeld (17).]

Zerbe (18) estimated a property value equation for Toronto and Hamilton, Ontario. Sulfur dioxide and dustfall were the two pollution measures used. Both linear and log-linear specifications were employed; in the log-linear specification, the elasticity of property values with respect to sulfur dioxide ranged from 0.061 to 0.121 for Toronto and 0.081 for Hamilton.*

Crocker (19), in a study of the relationship between home sale price and sulfur dioxide and particulates in Chicago, found a significant negative relationship between sale price and particulate matter when both pollution variables were entered into the equation. When each pollution variable was entered separately, they both exhibited a significant negative relationship with sale price.

Anderson and Crocker (24) estimated the relationship between air pollution and median property values (estimated by owner) for three cities: St. Louis, Washington, D.C., and Kansas City. Using separate equations for owner-occupied and renter-occupied housing, they found a significant negative relationship between air pollution and property values while controlling for median family income, percentage of old units, percent of run-down units, percent of non-white population, distance to the central city, and median number of rooms. Using a log-linear specification, they found that the mean property value for the St. Louis area would be reduced by $300 to $700 for an increase at the mean of 0.1 $\mu g/100\ cm^2/day$ in SO_3 and a 10 $\mu g/m^3$ increase in particulates.

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* Information on the studies by Zerbe (18), Crocker (19), and Steele (20) is taken from Freeman (21), Waddell (22), and Appel (23).

Steele (20) did not find a significant relationship between property values, as measured by mean value per room, and SO_2 and particulates.

Wieand (25) regressed per-acre housing expenditures in St. Louis (a proxy for land values) on property characteristics, neighborhood characteristics, income, and pollution as measured by annual mean sulfation and annual mean particulates. Neither pollution variable was significant.

Deyak and Smith (26), using a log-linear specification, found a significant relationship between median property values of representative SMSAs and suspended particulates. Other variables included in their best equation were median family income and percent of inferior housing units. In a later study on the owner- and renter-occupied housing market for 85 cities which included measures of local public services and taxes, Smith-Deyak (27) did not find a significant negative relationship between air pollution and property value. A possible reason for their failure to find a significant negative relationship between air pollution and property values may be due to the fact that property value differentials were examined across, rather than within, cities.

Using the data from Anderson and Crocker's St. Louis study (24), Polinsky and Rubinfeld (28) empirically estimated the equilibrium housing market function developed by Polinsky and Shavell (9) using a Cobb-Douglas form of utility function. Log-linear equations were developed for both owned and rented properties. The suspended particulate variable was negative and significantly different from zero at the 0.05 level for both equations, while the sulfur oxide variable was negative and significantly different from zero at the 0.10 level for the homeowner equation.

The concentration of nitrogen oxides, NO_x (used as a proxy for air pollution), was found to be negatively related to median property values in Boston by Harrison and Rubinfeld (7). Besides air pollution, the housing characteristics that were included in the equation were: two structural variables, eight neighborhood variables, and two accessibility variables. With all the independent variables at their mean levels, a change in NO_x of 1 pphm was associated with a change in median housing values of $1,613. They also estimated a willingness-to-pay equation and found that the marginal willingness to pay for air quality improvements varied a great deal depending on the existing level of air pollution and income.

Nelson (8) also found a significant relationship between air pollution and median census tract owner-occupied property values in Washington, D.C. Several different specifications were employed with the semi-log and log-linear forms giving the best results. It was concluded that an increase in the mean level of total suspended particulates of 10 $\mu g/m^3$ would reduce the mean value of property by \$576 to \$693, and an increase in the mean oxidant level of 0.01 ppm would reduce the mean value of property by an additional \$141 to \$152. The estimated marginal willingness to pay was then used to calculate the demand curve for air quality.

In a study of single-family owned residences in the Los Angeles area, Brookshire et al. (29) found a significant negative relationship between the sale price of homes and air pollution measures. Actual market transactions for individual homes were used as the unit of observation. Both the linear and nonlinear specifications employed showed a significant relationship between home sale price and pollution. The average sale price differential attributable to a change in the level of pollution from "poor" to "fair" ranged from \$5,793 per home to \$6,134 per home.

In a study of the New York metropolitan area, Appel (23) found a significant negative relationship between suspended particulates and mean property values. The hedonic equation that performed best was one in which the pollution variable was entered in exponential form. This form conforms to a priori expectations that the marginal damages of pollution increase as pollution increases. Other variables included in the best equation were the mean number of rooms, the crime rate, the percent of non-white persons, and minutes of time to the central business district.

A summary of the studies that have found a significant negative relationship between residential property values and air pollution is given in Table 5-2.

LIMITATIONS OF THE HEDONIC TECHNIQUE

Before proceeding with the calculation of benefits, it is important to reiterate the limitations of using the hedonic technique and the effect these limitations have on the ability to predict the benefits of improvements in air quality. The hedonic technique is capable of estimating the implicit price of the characteristics of a good that the consumer is able to accurately perceive. Since most characteristics of a good are tangible and easily perceived, this is not unreasonable. Air quality, *per se*, is not a tangible characteristic of housing and it is possible that households are unable to accurately perceive the effect of air quality on their residential property. Even if households are cognizant of some of the effects of air quality, it is doubtful that they will be aware of all of its effects. Consequently, all of the effects of air quality may not be capitalized into residential property values. Application of the hedonic technique in order to estimate the effects of air pollution may therefore result in an underestimate of the "true

TABLE 5-2. REVIEW OF PROPERTY VALUE STUDIES

Study	City; dependent variable	Pollutants measured, method of measurement	Form	Elasticities of pollution variables (at means)	Estimated benefits; base year
Ridker & Henning (11)	St. Louis; MPV[a]	Index of sulfation	Linear	N.A.[b]	If sulfation falls by 0.25 μg/100 cm^2/day, MPV increases by $186.50 to $245.00; 1960
Zerbe (18)	Toronto and Hamilton, Canada; MPV	Annual average and median of averages for sulfation (lead candle) in both cities. Annual average and median of averages for dustfall in Toronto.	Linear and log-linear	Log-linear equation: Sulfation: Toronto -0.061 to -0.121 Hamilton -0.081	At the mean, a decrease of 1 mg SO_3/100 cm^2/day would increase mean property value by a maximum of $97 in Toronto; 1961
Crocker (19)	Chicago; home value given by sale price	Annual arithmetic mean for sulfation (lead candle) and particulates	Log-linear	Equation with both pollutants: Particulates: -0.2 to -0.5 Sulfation: 0.06[c]	At the mean, a reduction of 10 μg/m^3 in particulates and 1 ppb of SO_2 would lead to a $350 to $600 increase in the mean value of property; 1964-1967
Peckham (30)	Philadelphia; MPV	One-month average for sulfation and arithmetic mean for particulates	Linear and log-linear	Log-linear equation: Sulfation: -0.096 Particulates: -0.116	At the mean, a decrease in SO_3 of 0.1 mg/100 cm^2/day and a 10 μg/m^3/day in suspended particulates leads to an increase in the mean property value of $600 to $750; 1960
Anderson & Crocker (13)	Washington, DC, St. Louis and Kansas City; MPV median gross rent and median contract rent	Annual arithmetic mean for concentrations of SO_x (measured by lead candle) and particulates	Log-linear	Owner-occupied equation: Sulf. Part. D.C. -0.07 -0.06[c] K.C. -0.08 -0.09[d] S.L. -0.10 -0.12[d]	At the mean, a reduction of 1 mg SO_3/100 cm^2/day and a 10 μg/m^3/day in suspended particulates would increase mean property value of owner-occupied housing by $300 to $700 in Washington, D.C.; 1960
Spore (31)	Pittsburgh; MPV	Annual geometric means and maximum monthly values for sulfation (lead candle) and dustfall	Log-linear	Sulfation: 0.03[d] Dustfall: -0.12	A reduction of 0.005 ppm/day in SO_2 and 5 tons/mi^2/month in dustfall increases the value of mean property by $150 to $200; 1970
Polinsky & Rubinfeld (28)	St. Louis; MPV, median gross rent and median contract rent	Same as Anderson & Crocker (1971)	Log-linear	Owner-occupied equation: Sulfation: -0.063[c] Particulates: -0.132	A 5% reduction in sulfation and particulate levels in all areas of St. Louis would lead to a predicted change in aggregate property values of $55 million; 1960

(continued)

TABLE 5-2 (continued)

Study	City; dependent variable	Pollutants measured, method of measurement	Form	Elasticities of pollution variables (at means)	Estimated benefits; base year
Harrison & Rubinfeld (7)	Boston; MPV	Mean concentrations for nitrogen oxide and particulates calculated by a dispersion model	Exponential semi-log	Nitrogen oxide: -0.39	Mean value of property would increase by $1,613 if the oxidant concentration decreased by 0.01 ppm; 1970
Nelson (8)	Washington, DC; MPV	Monthly geometric mean of particulates and arithmetic average of means of oxidant levels	Log-linear	Particulates: -0.048 to -0.116 Oxidants: -0.007 to -0.019	At the mean, a decrease in particulates of 10 $\mu g/m^3$ increases the value of mean property by $576 to $693. At the mean, a decrease in oxidants of 0.001 ppm increases the value of mean property by $141 to $152; 1970
Brookshire et al. (29)	South Coast Air Basin in California; sale price of individual houses	Arithmetic average for nitrogen dioxide and particulates	Linear and semi-log	N.A.	At the mean, a decrease of 1 pphm in nitrogen dioxide would result in an increase in the mean sale price of housing of $2,010; 1977-1978
Appel (23)	New York Metropolitan Area; mean property value of single family owner-occupied housing	Geometric mean of suspended particulates	Exponential	Particulates: -0.039	The average benefit (weighted by the number of households exposed to alternative pollution levels) for a 1 $\mu g/m^3$ reduction in suspended particulates is $42.13; 1970

[a] MPV is median property value of single family owner-occupied housing units in a census tract.

[b] The mean values of pollution and property values were not reported; consequently, the elasticities could not be estimated.

[c] Not significantly different from zero at 0.05 level.

[d] Not significantly different from zero at 0.01 level.

benefits" accruing to residential properties.* Although there has been some criticism that the hedonic technique is invalid for predicting the benefits of air quality improvement because households are unable to accurately perceive _any_ of the effects of air pollution, the studies in Table 5-2 appear to support the hypothesis that households perceive at least some of the effects of air pollution and these effects are capitalized into property values.

Benefits estimated through hedonic property value equations may only provide estimates of the perceived benefits that occur at the _residential property_. Some of the benefits from air quality improvements that occur away from home (e.g., at the workplace, recreational areas) may not be capitalized into residential property values. Since a portion of the household's time is spent away from home, it is possible that only a portion of the total benefits accruing to a household may be predicted from the hedonic property value equations. This must be kept in mind when comparing benefits estimated by the hedonic technique to benefits estimated by other methods.

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* It is also possible, on the other hand, that benefits may be overestimated if households, because of their lack of knowledge of the true effects of air pollution, overcompensate for the effects of air pollution through their valuations of properties exposed to different levels of air pollution.

As mentioned in the last subsection, the assumptions that are necessary in order for the hedonic equation to estimate the marginal willingness to pay for air quality improvements are:

- Individuals must be able to perceive the characteristics and attributes of housing.
- The housing market must be in equilibrium.
- A complete range of houses with alternative characteristics must be available.

It is very unlikely that these conditions will hold in the housing market. In this study, we are mainly concerned with how the violation of these assumptions will affect the estimated air pollution-property value relationship. The violation of the first of these three assumptions has already been addressed in the discussion on the difficulty of applying the hedonic technique to a good possessing a characteristic such as air quality.

In order for the second assumption to be met in the housing market, households must be just willing to hold the existing stock of housing at the prevailing prices. Equilibrium will be achieved only if: 1) all households have complete information on the prices and characteristics of housing, 2) transactions and moving costs are equal to zero, and 3) housing prices adjust instantaneously to changes in demand and supply. According to Freeman (32), divergencies from equilibrium, in most cases, will only result in random errors in marginal willingness-to-pay estimates. Freeman mentions, however, that less than instantaneous adjustment in the housing market to changes in demand or supply may result in biased estimates of the air quality variable. For example, if equilibrium is disrupted due to an air quality change, and transactions and moving costs are non-zero, households will not move unless the benefit is at least as great as the costs involved in moving. If air quality is consistently changing in one direction and households consistently lag in their adjustment to that change, the observed marginal implicit price will diverge from the true marginal willingness to pay. In this case, the marginal implicit price of air quality identified in the hedonic property value equation is a biased estimate of the equilibrium marginal willingness to pay.

Freeman also mentions that future expectations on housing prices may result in biased estimates of the implicit price of air quality. If households perceive that an improvement in air quality will take place in the future and housing prices are affected by that perception, the market has adjusted to the air quality change before the change actually takes place. If a hedonic price equation is specified for the housing market in an area that has already adjusted to a future air quality change, the marginal willingness to pay for air quality would be underestimated.

It is quite possible that the third assumption may be violated due to the nature of the housing market. Given the time necessary for the supply of housing to adjust to changes in demand, it is likely that some households will not be able to find housing with all of the characteristics that the household finds desirable. In these households, utility cannot be maximized. Whether this is a problem that will seriously affect the estimates of the marginal implicit price of air quality has not been investigated at the present time. It is doubtful, however, that the existence of an incomplete range of homes in the study area will make the estimated relationship between air pollution and property values totally unreliable.

Segmentation in the housing market can also affect the estimates of the marginal implicit prices of housing attributes. Housing market segmentation exists when the purchasers of housing participate in distinctly separate housing submarkets even though the purchasers are technically participating in the same housing market. The submarkets may exist because of racial discrimination, cultural differences, or geographic immobility. Where housing market segmentation exists, the structure of the prices of housing in each submarket will be different. The specification of a hedonic price function for one housing market when submarkets exist will result in incorrect estimates of the marginal implicit prices of housing attributes. In order for the implicit prices of housing characteristics to be correctly estimated, separate equations for each submarket must be used. Harrison and Rubinfeld (7) have found that separating their sample into submarkets did affect their benefit estimates for Boston, while Nelson (33) did not find that stratified samples for the Washington, D.C. area affected the hedonic price functions. Further research investigating this problem is needed before anything more conclusive can be said regarding the effect of market segmentation on the hedonic price functions.

Certainly, one should not conclude that the benefits estimated using the hedonic price technique are meaningless because of the caveats that must be attached to the technique. A negative relationship between air pollution and property values has been consistently shown to exist. In addition, the marginal implicit prices of air pollution estimated in different studies are consistent and quite plausible. The technique is definitely useful in providing approximate estimates of the magnitude of some of the benefits of air quality improvement.

BENEFIT ESTIMATES

The studies reviewed in the Literature Review subsection provided estimates of the willingness to pay for marginal air quality improvements for specific cities. In this section, we will assume that these studies are representative of the 24 SMSAs examined in this study and will use the results to estimate the benefits of achieving alternative secondary standards for these 24 SMSAs. It should be noted that there are a number of reasons why a strict comparison of the results of the studies reviewed in the Literature Review subsection is not possible. These reasons can be explained by referring to Table 5-2. Although the majority of studies use the median property value of a census tract as the dependent variable in their equations, Crocker (19) and Brookshire et al. (29) use the sale price of individual homes. Most studies have concentrated on only the owner-occupied housing market, while some studies have also estimated equations for the rental market using median gross rent and median contract rent as dependent variables.

The pollutants measured also differ among studies. Sulfur oxides, particulate matter, dustfall, and nitrogen oxides are used in various studies. Because of the high correlation that tends to exist among pollutants, it is difficult to tell whether the effect on property values of a particular pollutant, or just pollution in general, is being measured. When two highly correlated pollutants are entered as independent variables in the same equation, it is difficult to isolate the separate effects of each of the pollutants on property values. If only one of the highly correlated pollutants is entered into the property values equation, on the other hand, its coefficient is probably picking up the effects of both the included and excluded pollutant. In Zerbe's study (18) on Hamilton property values, for example, it is difficult to tell whether the coefficient of sulfation is also measuring the effect of particulate matter on property values.

In addition to the various pollutants measured, the studies in Table 5-2 also differ in that the pollutants are measured in different units. Annual means, monthly means, maximum values, geometric means, and arithmetic means are the units used to measure the pollution variables. The techniques used to measure pollution also vary among the studies. Although most of the studies have used estimates of sulfation that were measured by the lead candle technique, this technique is not strictly comparable to the techniques that are currently in use. In fact, the lead candle technique tends to bias the sulfation measurements in an unknown direction.*

The results of the studies reviewed in Table 5-2 are based on data collected in different years (e.g., 1960 and 1970 Census data). This is not likely to be a problem in comparing the studies because the demand for air quality probably has not changed significantly over the years in which these studies were done. However, the benefits estimated by the studies using data from different years are obviously not comparable because of the differences in property values due to increases in the price level. For this reason, the comparison of the results of the property value studies will be based on the estimated coefficients and elasticities of the air pollution variables.

As can be seen in Table 5-2, all but one of the studies have used a nonlinear functional form to estimate the relationship between air pollution and property values. The choice of a nonlinear specification in the studies employing the hedonic technique can be viewed as being twofold. The hedonic equation need not be linear if costless repackaging of the characteristics of the good is impossible.

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* As per phone conversation with John Clements of USEPA.

In the housing market, it is unlikely that costless repackaging of the characteristics of housing will be common. For example, two homes with four sides are not equal to one home with eight sides. In addition, the hedonic equation may be nonlinear in the air quality variable depending on the assumptions regarding the marginal implicit price of air quality. If the hedonic equation is linear in the air quality variable, its marginal implicit price is constant over the entire range of air quality. Since there is no variation in the implicit price of air quality, it is not possible to identify the demand for air quality. In those hedonic studies where both linear and nonlinear specifications have been tried in order to measure the implicit price of air quality within a specific geographical area (e.g., SMSA), the nonlinear specifications have given more satisfactory results.

The majority of studies listed in Table 5-2 have used a log-linear functional form to specify a nonlinear relationship between air pollution and property values. A significant negative relationship between air pollution and property values has been found in the majority of these studies. Unlike the marginal implicit price of air pollution in a linear specification, the marginal implicit price in these specifications varies depending on the ratio of the property value to the pollution level.* Of more interest, however, is the rate of change of the marginal implicit price schedule. It is positive for a log-linear specification, implying that the marginal implicit price (a negative) is an increasing function of the level of pollution. Since pollution is something to be avoided (i.e., a disamenity), this means that the marginal willingness to pay to avoid pollution becomes less negative as pollution increases; in other words, the marginal willingness to pay to avoid pollution is lower as the level of pollution rises. Intuitively, one would expect that the higher the level of pollution, the greater the willingness to pay for a marginal improvement in air quality. Both Harrison and Rubinfeld (7) and Appel (23) employ specifications that yield negatively-sloped marginal implicit price curves that conform to the *a priori* expectation that the marginal willingness to pay to avoid air pollution is greater for higher levels of pollution.

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* The first derivative of the log-linear specification, (Property Value) = a(Pollution)^b, is b (Property Value/Pollution).

Since the hedonic technique examines the *equilibrium* relationship between property values and air pollution, it is not clear whether the positive slope of the marginal implicit price curve results from the fact that people living in relatively clean air environments may tend to have larger incomes, and consequently a higher equilibrium marginal willingness to pay for additional air quality improvements, than poorer people who may tend to live in relatively dirty air environments. Not enough empirical research has been done in this area, however, to justify the hypothesis that the marginal implicit price curve is negatively sloped.

As mentioned in the Methodology subsection, the hedonic price technique yields only the equilibrium willingness to pay for marginal improvements in air quality. Moving from the primary to secondary standard, however, will involve non-marginal changes. In order to accurately estimate the benefits of these changes in air quality, the demand price function of consumers for air quality must be known. This function can be calculated using the implicit prices estimated by the hedonic technique, and information on air quality levels, consumer income and characteristics. Since such information is lacking at this time for the majority of the property value studies, we will approximate the benefits of these non-marginal reductions based solely on the information yielded by the hedonic price technique.

The benefits of achieving the secondary standard will be approximated using the results of the studies listed in Table 5-2. The marginal implicit price curve for air quality for the log-linear specification is shown in Figure 5.3.* MPV'(P) is a plot of the derivative of the housing equation with respect to air pollution and also traces out the equilibrium willingness to pay to avoid air pollution. D(P) is the true demand curve for air pollution. Since air pollution is a "bad", a large negative price implies that the household is willing to pay large amounts to avoid air pollution. Note that the marginal implicit price curve resulting from the log-

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* Since this is the most common specification used in the studies listed in Table 5-2, it will be used for explanatory purposes.

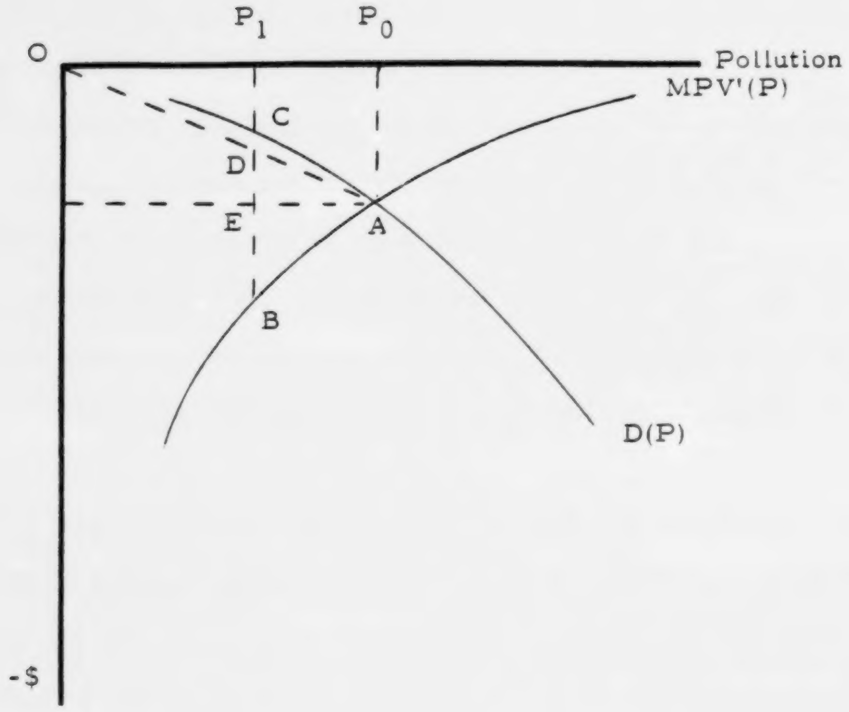

Figure 5-3. Alternative benefit estimates for a given change in air quality.

linear specification implies that the marginal implicit price of air pollution increases (becomes less negative) as pollution increases.

The benefits of an improvement in air quality can be estimated by the area under the demand curve over the range of improvement. For the improvement in air quality from P_0 to P_1 that is shown in Figure 5-3, the benefits are estimated by the area AP_0P_1C. The demand curve for air quality has not been estimated in this analysis, however, and it is necessary to rely on information contained in the hedonic price equations to approximate the benefits of an improvement in air quality. The benefits of an improvement in air quality from P_0 to P_1 can be approximated by the area under the marginal implicit price curve, AP_0P_1B. It must be kept in mind that this approximation implies that all households' marginal willingness-to-pay functions are identical and increasing in pollution abatement.* Clearly, this is an overestimate of the true benefits of improvement.

Freeman (34) has suggested two alternative ways of approximating the benefits of non-marginal changes in air quality when the demand curve for air quality is not known. By assuming that the household's marginal willingness to pay for air quality is constant over the entire range of air quality, household benefits can be approximated by the area AP_0P_1E. The benefits represented by this area can be estimated by:

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* The marginal implicit price function will necessarily be increasing in pollution abatement only for log-linear specifications. The linear specification of the property value equation will result in a constant marginal implicit price. Exponential, semi-log exponential, quadratic, and the Box-Cox transformation may yield marginal implicit price curves that are decreasing in pollution abatement.

$$\text{Benefits} = \frac{\partial \text{Property Value}}{\partial \text{Pollution}} (\Delta \text{Pollution}) \tag{5.15}$$

For the log-linear specification, this is equivalent to:

$$\text{Benefits} = b \frac{\text{Property Value}}{\text{Pollution}} (\Delta \text{Pollution}) \tag{5.16}$$

where b = the estimated coefficient of the pollution variable in the hedonic equation.

If the true demand curve for air pollution is D(P), this approximation technique will result in an overestimate if the marginal implicit price function is increasing in pollution abatement. However, this technique clearly will result in a closer approximation of true benefits estimated by the area AP_0P_1B.

The other alternative is consistent with the _a priori_ expectation that the marginal willingness to pay for air pollution abatement declines as air quality improves. One point on the household's demand curve for air quality is known from the hedonic price equation. By assuming that the household's marginal willingness to pay for air pollution abatement declines linearly from that point to a zero marginal willingness to pay when air pollution has been completely abated, benefits can be approximated for a given improvement in air quality. For the reduction in air pollution from P_0 to P_1 shown in Figure 5-3, household benefits can be approximated by the area AP_0P_1D. The benefits represented by this area can be easily calculated as the difference in triangle OP_0A and OP_1D. This area can be approximated by:

$$\text{Benefits} = \frac{1}{2}[(P_0A \cdot OP_0) - (P_1D \cdot OP_1)] \qquad (5.17)$$

For the log-linear specification, this is equivalent to:

$$\text{Benefits} = \frac{b}{2}\text{ Property Value}\left[1 - \frac{(\text{Pollution}_1)^2}{(\text{Pollution}_0)^2}\right] \qquad (5.18)$$

where Pollution_0 = initial pollution level

Pollution_1 = pollution level after an air quality change.

Depending on the shape of the actual demand curve for air quality, the approximation of benefits under the assumption of a linearly declining marginal willingness to pay curve can result in either an underestimate or overestimate of true benefits.

Obviously, either of these alternatives will result in closer estimates of the true benefits of a given air quality improvement than the benefits estimated by the area under the marginal implicit price curve of the log-linear hedonic property value specification. The linearly declining marginal willingness-to-pay alternative, however, is consistent with the a priori assumption that the household's marginal willingness to pay for air pollution abatement declines as air quality improves. Because it can be assumed that the majority of health benefits are captured in moving to the primary standard, it seems reasonable to expect that the marginal willingness to pay for further air quality improvements will be decreasing. For this reason, we will calculate the benefits of proposed secondary standards using the linear to the origin technique.

Assuming the secondary standard will be set in terms of sulfur dioxide (SO_2) and total suspended particulate matter (TSP), we will concentrate on the studies that have examined the effect of one or both of these pollutants on property values. Allowing for the differences among the studies reviewed in Table 5-2, the results of these studies have been remarkably consistent. The elasticities of the sulfur oxide variables range from a low of -0.061 to a high of -0.12, with a more likely range being -0.07 to -0.10.* The particulates' elasticities range from -0.039 to -0.5, with the more likely range being -0.05 to -0.12.*

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* The elasticity is a measure of the percentage change in one variable that can be expected from a given percentage change in another variable. In this case, it is the percentage change in property value that can be expected from a given percentage change in pollution. An elasticity of 0.1 means that a 10 percent change in air pollution will result in a 1 percent change in property values.

As can be seen in Table 5-2, these ranges of elasticities correspond to the studies employing log-linear specifications. Household benefits will therefore be approximated using Equation (5.18).

Benefits of achieving alternative secondary standards will be calculated for the 24 SMSAs listed in Table 5-3. Household benefits in a particular SMSA will be calculated for the single-family owner-occupied household with median property value that is exposed to the average level of pollution within the SMSA. For the purposes of this analysis, the benefits accruing to this household will be taken as representative of the benefits accruing to households residing in rental and multiple-dwelling units. This may lead to an overestimate or underestimate of benefits if the willingness to pay for air quality improvements tends to be different for the households residing in these types of structures. Similarly, benefits may be under- or overestimated if the majority of the housing units in an SMSA are exposed to pollution levels that are different from the average level

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* The particulate elasticity of 0.039 reported by Appel (23) is based on an exponential specification. Unlike the elasticities reported in those studies employing log-linear specifications, this elasticity varies depending on the level of particulates. For example, if the mean level of particulates from Nelson's study on Washington, D.C. is used with Appel's estimated pollution coefficient, the elasticity increases to -0.067.

TABLE 5-3. SMSA'S INCLUDED IN PROPERTY VALUE STUDY

Atlanta	Denver	New York
Baltimore	Detroit	Philadelphia
Boston	Honolulu	Pittsburgh
Buffalo	Houston	St. Louis
Chicago	Kansas City	San Diego
Cincinnati	Los Angeles	San Francisco
Cleveland	Milwaukee	Seattle-Everett
Dallas	Minneapolis-St. Paul	District of Columbia

for the SMSA.* With these qualifications in mind, the benefits of achieving the secondary standard for the 24 SMSAs listed in Table 5-3 are:**

$$\text{Benefits} = \sum_{i=1}^{24} (\text{No. of housing units in SMSA}_i) \cdot (\text{Benefits per housing unit of meeting the secondary standard in SMSA}_i)$$

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* In the case of the Chicago SMSA, for example, the benefits of the reduction in TSP levels will be underestimated using the average TSP level within the SMSA since 80 percent of the SMSA population live in areas where the TSP levels exceed the SMSA average.

** Although the national benefits will exceed the benefits estimated for the 24 SMSAs, we will limit our benefit estimates to these 24 since the purpose of this section is to provide a cross-check on the benefits estimated by the household expenditure model.

The scenario for reaching the secondary standard is identical to the one used in previous sections; i.e., air quality in the SMSAs will improve by half of the amount necessary to reach the secondary standard by the end of 1986 and the remaining improvement by the end of 1987. It is also assumed that these improvements in air quality will be instantaneous, occurring on the last day of 1986 and 1987. In addition, any SMSA that was in excess of the primary standard in 1978 is assumed to be meeting the primary standard in 1985 and benefits will be estimated for the change in pollution from the primary to secondary standard. Benefits for any SMSA that had a level of pollution in 1978 that was less than the primary standard but more than the secondary standard will be based on the change in pollution from the 1978 level to the secondary standard. Any SMSA that was meeting the secondary standard in 1978 is assumed to be meeting it in 1985. Consequently, no benefits are calculated for these SMSAs. This may underestimate benefits if air quality in these SMSAs has deteriorated since 1978.

Because the alternative secondary standards used in this study are couched in terms of the mean and 24-hour maximum, we will calculate benefit estimates for compliance with these standards:

	Alternative Secondary Air Quality Standard* ($\mu g/m^3$)
SO_2:	
Annual arithmetic mean	60
24-hour maximum**	260
TSP:	
Annual geometric mean	60
24-hour maximum**	150

Obviously, the benefits estimated from the reduction in the means and maximum values are not additive and should be viewed as alternative measures of the benefits in meeting the secondary standard. A detailed explanation of how the benefits are estimated is given in Appendix 5-A. Appendix 5-B provides estimates of the benefits in reducing air pollution, broken down by SMSA.

Tables 5-4 through 5-7 give the benefits, in discounted present value, of the reduction in air pollution to the secondary standard using different measures of air pollution. As Tables 5-4 and 5-5 show, the discounted present value of the benefits in reducing the mean level of TSP and SO_2 to 60 $\mu g/m^3$ is in the range of $2.41 to

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* The standards listed above are not, in all cases, part of the current Federal regulations. The source of the standards shown here is Stern *et al.* (35), p. 159.

** This value is not to be exceeded more than once a year.

TABLE 5-4. ESTIMATED BENEFITS OF THE REDUCTION IN TOTAL SUSPENDED PARTICULATE MATTER TO ALTERNATIVE SECONDARY STANDARDS*
(in discounted present value billions of 1980 $)**

Reduction in:	Total benefits (in billion $)	Average benefit per household (in $)
Annual average to 60 $\mu g/m^3$	$2.08 - $4.99	$ 71 - $170
Average of second highest values to 150 $\mu g/m^3$	$3.53 - $8.47	$120 - $289

* Benefit calculations based on 24 SMSAs.

** Assuming a 10 percent rate of discount.

TABLE 5-5. ESTIMATED BENEFITS OF THE REDUCTION IN SULFUR DIOXIDE TO ALTERNATIVE SECONDARY STANDARDS*
(in discounted present value in billions of 1980 $)**

Reduction in:	Total benefits (in billion $)	Average benefit per household (in $)
Annual average to 60 $\mu g/m^3$	$0.33 - $0.47	$ 14 - $ 19
Average of second highest values to 260 $\mu g/m^3$	$1.14 - $1.62	$ 48 - $ 69

* Benefit calculations based on 19 SMSAs.

** Assuming a 10 percent rate of discount.

TABLE 5-6. ESTIMATED BENEFITS OF THE REDUCTION IN TOTAL SUSPENDED PARTICULATE MATTER TO ALTERNATIVE SECONDARY STANDARDS* (discounted present value in 1980 $)**

Reduction in:	Total benefits (in billion $)	Average benefit per household (in $)
Maximum annual average within SMSA to 60 $\mu g/m^3$	$ 7.64 - $18.32	$260 - $ 626
The second highest value within SMSA to 150 $\mu g/m^3$	$13.40 - $32.16	$457 - $1,098

* Benefit calculations based on 24 SMSA's.

** Assuming a 10 percent rate of discount.

TABLE 5-7. ESTIMATED BENEFITS OF THE REDUCTION IN SULFUR DIOXIDE TO ALTERNATIVE SECONDARY STANDARDS* (discounted present value in 1980 $)**

Reduction in:	Total benefits (in billion $)	Average benefit per household (in $)
Maximum annual average within SMSA to 60 $\mu g/m^3$	$ 3.20 - $ 4.57	$136 - $ 194
The second highest value within SMSA to 260 $\mu g/m^3$	$ 5.98 - $ 8.54	$255 - $ 364

* Benefit calculations based on 19 SMSA's.

** Assuming a 10 percent rate of discount.

$5.46 billion for the 24 SMSAs of the study.* Per-household benefits are in the range of $71 to $170 for the reduction in TSP and $14 to $19 for the reduction of SO_2.** The estimated benefits increase to a range of $4.67 to $10.09 billion when the reduction in pollution is in terms of the average of the second-highest values. Per-household benefits ranging from $120 to $289 for TSP and $48 to $69 for SO_2 are also calculated.

Upper-bound benefit estimates are calculated using the maximum pollution reading within an SMSA as representative of the reduction in pollution for the entire SMSA. Benefits are calculated for the maximum annual average and the second highest pollution readings within each SMSA for both TSP and SO_2. Tables 5-6 and 5-7 give the results of these calculations. Benefits in the range of $10.84 to $22.8 billion are calculated for the reduction in maximum annual averages of TSP and SO_2 within an SMSA to the secondary standard. This translates into per-household benefits of approximately $200 to $626 for TSP and $136 to $194 for SO_2. Using the second highest TSP and SO_2 readings within an SMSA as representative of the pollution level within the SMSA, benefits increase to a range of $19.38 to $40.70 billion, or per-household benefits of $457 to $1,098 for TSP and $255 to $364 for SO_2.

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* Data on SO_2 are available for only 19 of the 24 SMSAs in the study. SO_2 readings were not available for the Atlanta, Baltimore, Honolulu, Los Angeles, and Seattle SMSAs. The benefits, therefore, may be underestimates of the total benefits that would be estimated by the property value analysis if any of all of these SMSAs exceeded the secondary standard in 1978.

** Per-household benefits of the reductions in TSP and SO_2 will be kept separate because these calculations are based on different numbers of households.

Because these estimates are based on studies that generally examine the relationship between property values and pollution in terms of the annual average of pollution, benefits in the range of $2.41 to $5.46 billion are considered to be the best estimates.

CONCLUSION

In this analysis, the discounted present value of the benefits in reducing TSP and SO_2 levels to comply with the proposed secondary standards has been estimated using the results of past property value differential studies. The benefits from the reduction in TSP have been estimated for 24 SMSAs which comprise about 32 percent of the United States' population. Benefits calculated for the reduction in SO_2 are based on 19 SMSAs which comprise about 28 percent of the population. Using the linear to the origin approximation technique, a reduction in the annual arithmetic mean of SO_2 and the annual geometric mean of TSP to 60 $\mu g/m^3$ has been estimated to result in benefits of $2.41 to $5.46 billion for the 24 SMSAs in the study. Viewed in terms of the reduction in the average of the second highest reading in an SMSA to 260 $\mu g/m^3$ and 150 $\mu g/m^3$ for SO_2 and TSP, respectively, the benefits increase to a range of $4.67 to $10.09 billion. These estimates are gross approximations of the benefits in meeting the secondary standard for basically four reasons: (1) the results of studies on specific cities in the early 1960's and 1970's are used to estimate the benefits of pollution reductions occurring in 1986 and 1987 for 24 SMSAs; (2) the benefits of the air quality improvements are approximated without knowledge of the true demand curve for air quality; (3) the marginal willingness to pay for air quality improvements of households residing in single-family units is assumed to be representative of the marginal willingness to pay of all households; and (4) the average of the air pollution readings in an SMSA is taken as representative of the level of exposure of all households in the SMSA. If the majority of households in an SMSA are located in areas that are exposed to levels of air pollution that are beneath the SMSA average, benefits will be overestimated. Conversely, if households are typically located in the "polluted" areas of the SMSA, benefits will be underestimated. These estimates are useful, however, because they provide some idea of the magnitude of the "property value" benefits that will be obtained when moving from the primary to the secondary standard.

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APPENDIX 5-A

CALCULATION OF BENEFITS

Benefits were calculated in the following manner:

1. Any SMSA that had TSP and/or SO_2 levels exceeding the primary standard in 1978 was assumed to be meeting the primary standard in 1985. In these cases, the reduction in pollution was measured in terms of the movement from the primary to secondary standard. Any SMSA that had a pollution level beneath the primary standard in 1978 was assumed to remain at this level until 1985 and the reduction in pollution was measured in terms of the movement from the 1978 level to the secondary standard.

2. The decrease in pollution necessary to reach the secondary standard in 1987 was assumed to occur in two stages. Half of the decrease was assumed to occur on the last day of 1986 and the other half of the decrease was assumed to occur on the last day of 1987. For example, the average of the annual geometric means of TSP for the monitoring stations in the Pittsburgh SMSA was 82.33 $\mu g/m^3$*. This level exceeds the primary standard of 75 $\mu g/m^3$. Assuming compliance with this standard in 1985, the reduction in TSP in Pittsburgh

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* Throughout this appendix, the Pittsburgh SMSA will be used as an example of the calculations. Pittsburgh and the Pittsburgh SMSA will be used interchangeably for the remainder of the example. The procedure used to measure the benefits from the reduction in the annual geometric mean of TSP to 60 $\mu g/m^3$ can also be used to measure the benefits of the reduction in the annual average of SO_2.

necessary to meet the secondary standard is 15 $\mu g/m^3$ or 7.5 $\mu g/m^3$ at the end of both 1986 and 1987.

3. The next step was to estimate property values in 1986 and 1987. Data on the median property value of owner-occupied single-family dwellings by SMSA were found in the Annual Housing Survey of the Bureau of Census. Using the Consumer Price Index for the "housing bundle" specific to each SMSA from 1970 to 1978, the average increase in the price of the housing bundle was calculated.* The Consumer Price Index for the housing bundle in the Pittsburgh SMSA was:

1970	118.9	1975	163.4
1971	125.5	1976	174.3
1972	129.7	1977	187.4
1973	134.2	1978	204.6
1974	147.3		

An average yearly increase in the price of the housing bundle of 7.05 percent was calculated for the Pittsburgh SMSA. The median property value of single-family owner-occupied dwellings in Pittsburgh was $22,400 in 1974. Using the actual yearly percentage increases in the housing bundle index from 1974 to 1978 and the average increase of

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* The housing bundle includes rent, home purchase, mortgage rates, property taxes, maintenance and repairs, fuel and other utilities, household furnishings, supplies, and operations. Although this index is not an exact measurement of the increase in property values, it is probably more representative of the increase than the Consumer Price Index for all goods.

7.05 percent per year from 1978 to 1987, the median property values estimated for Pittsburgh were:

	Median property value
1986	$49,900
1987	$53,400

4. Using the median property value estimated for 1986 and 1987, and the changes in and levels of particulate matter in those years, along with the estimated range of coefficients for particulate matter (i.e., 0.05 to 0.12), ranges of the dollar benefits for a single-family owner-occupied household were estimated according to the following formula:

$$\text{Benefits} = \frac{b}{2}\,\text{Property value}\left[1 - \frac{(\text{Pollution}_1)^2}{(\text{Pollution}_0)^2}\right]$$

> -- under the assumption that the household's marginal willingness to pay for air quality improvements declines linearly from the equilibrium point revealed from the hedonic price equation to the origin --

where b = the estimated coefficient of the pollution variable in a log-linear hedonic equation.

Pollution_0 = initial pollution level.

Pollution_1 = pollution level after an air quality change.

The range of household benefits in the Pittsburgh SMSA are therefore estimated to be:

Year	Benefits
1986	\$237.03 - \$568.86
1987	\$280.19 - \$672.44

Since the benefits were calculated from the change in property values, the estimates are in terms of the discounted present value (in 1986 and 1987) of the individual household benefits in reducing TSP to the secondary standard.

5. The benefits accruing to the household residing in a single-family owner-occupied residence were taken as representative of the benefits accruing to all households within an SMSA. Data on the projected number of households for 1986 and 1987 were not available by SMSA; therefore, the projected number of households in the United States and state populations for 1986 and 1987 were used to project the number of households in each SMSA for these years. These data were available from the Bureau of the Census Current Populations Reports, Series P-25. The estimated number of households in Pittsburgh were projected to be:

December 31, 1986	911,415
December 31, 1987	921,636

6. The benefits accruing to the SMSA were estimated by multiplying the number of households within the SMSA in 1986 and 1987 by the dollar benefits accruing to the individual household in 1986 and 1987. The benefits of the reduction in the SMSA average of the annual geometric mean of TSP to 60 $\mu g/m^3$ estimated for the Pittsburgh SMSA were:

Year	Benefits (in $1,000)
1986	$216,030 - $518,470
1987	$258,230 - $619,750

7. The final step was to express the benefits in 1980 dollars. This was accomplished by deflating the 1986 and 1987 benefit estimates by the housing bundle index derived for each SMSA. Using the 7.05 percent average increase in the price of the housing bundle for the Pittsburgh SMSA and a 10 percent discount rate led to discounted present value benefit estimates, in 1980 dollars, of:

Discounted present value benefits in thousands of 1980 $	$169,782 - $407,478

8. Benefits are calculated in the manner described in Steps 1 through 8 for each SMSA. Benefits are estimated using a 10 percent discount rate. The aggregate benefit estimates given in the text are obtained by aggregating across the various SMSAs.

APPENDIX 5-B

SMSA BENEFITS

The tables in this appendix list the benefits of attaining alternative secondary ambient air quality standards within each of the 24 SMSAs examined in this study. Tables B-1 through B-4 report the SMSA benefits of attaining alternative secondary standards for TSP, while Tables B-5 through B-8 report the benefits of attaining alternative secondary standards for SO_2.

TABLE B-1. ESTIMATED BENEFITS OF THE REDUCTION IN THE AVERAGE OF THE SECOND HIGHEST VALUES OF TSP WITHIN AN SMSA TO 150 $\mu g/m^3$* (discounted present value in thousands of 1980 $)

SMSA	Range Low	 High
Buffalo	$ 21,477	$ 51,546
Cleveland	150,995	362,389
Denver	367,127	881,107
Detroit	218,822	525,175
Houston	579,566	1,390,950
Kansas City	28,173	67,616
Los Angeles	1,630,070	3,912,191
Milwaukee	85,005	204,014
Pittsburgh	253,674	608,819
St. Louis	106,326	255,182
San Diego	87,307	209,537
Total	$3,528,542	$8,468,526

*Based on 24 SMSAs.

TABLE B-2. ESTIMATED BENEFITS OF THE REDUCTION IN THE ANNUAL AVERAGE GEOMETRIC MEAN OF TSP WITHIN AN SMSA TO 60 $\mu g/m^3$*
(discounted present value in thousands of 1980 $)

SMSA	Range	
	Low	High
Cleveland	$ 37,770	$ 90,648
Denver	195,366	468,878
Detroit	130,382	312,918
Houston	137,229	329,351
Kansas City	94,885	227,726
Los Angeles	905,386	2,172,927
Minneapolis	4,380	10,514
Pittsburgh	169,782	407,478
St. Louis	193,517	464,441
San Diego	209,191	502,060
Total	$2,077,888	$4,986,941

*Based on 24 SMSAs.

TABLE B-3. ESTIMATED BENEFITS OF THE REDUCTION IN THE MAXIMUM OF THE SECOND HIGHEST TSP WITHIN AN SMSA TO 150 $\mu g/m^3$*
(discounted present value in thousands of 1980 $)

SMSA	Range	
	Low	High
Atlanta	$ 58,495	$ 140,388
Baltimore	48,870	117,289
Boston	256,875	616,500
Buffalo	244,695	587,268
Chicago	1,749,360	4,198,475
Cincinnati	126,153	302,767
Cleveland	401,921	964,612
Dallas	386,258	927,020
Denver	411,425	987,422
Detroit	788,352	1,892,045
Houston	579,566	1,390,958
Kansas City	228,319	547,967
Los Angeles	1,905,079	4,572,190
Milwaukee	359,749	863,398
Minneapolis	553,704	1,328,891
New York	1,736,515	4,167,637
Philadelphia	824,255	1,978,214
Pittsburgh	357,159	857,183
St. Louis	407,113	977,072
San Diego	501,791	1,204,300
Seattle	336,970	808,728
District of Columbia	1,138,968	2,733,523
Total	$13,401,592	$32,163,847

*Based on 24 SMSAs.

TABLE B-4. ESTIMATED BENEFITS OF THE REDUCTION IN THE MAXIMUM OF THE ANNUAL GEOMETRIC MEANS OF TSP WITHIN AN SMSA TO 60 $\mu g/m^3$* (discounted present value in thousands of 1980 $)

SMSA	Range	
	Low	High
Atlanta	$ 230,699	$ 553,678
Baltimore	176,811	424,348
Boston	347,537	834,090
Buffalo	116,325	279,180
Chicago	831,578	1,995,788
Cincinnati	126,153	302,767
Cleveland	191,065	458,557
Dallas	250,668	601,603
Denver	195,366	468,878
Detroit	374,739	899,375
Houston	275,413	660,992
Kansas City	103,525	260,461
Los Angeles	905,386	2,172,927
Milwaukee	170,983	410,361
Minneapolis	263,179	631,630
New York	1,217,400	2,921,762
Philadelphia	404,656	971,174
Pittsburgh	169,782	407,478
St. Louis	193,517	464,441
San Diego	238,479	572,350
San Francisco	145,699	349,677
Seattle	160,164	384,395
District of Columbia	541,279	1,299,071
Total	$7,635,403	$18,324,983

*Based on 24 SMSAs.

TABLE B-5. ESTIMATED BENEFITS OF THE REDUCTION IN THE AVERAGE OF THE SECOND HIGHEST VALUES OF SO_2 WITHIN AN SMSA TO 260 $\mu g/m^3$* (discounted present value in thousands of 1980 $)

SMSA	Range	
	Low	High
Buffalo	$ 84,997	$ 121,425
Cleveland	79,185	113,122
Milwaukee	311,687	445,268
Minneapolis	529,176	755,965
Pittsburgh	130,910	187,015
Total	$1,135,955	$1,622,795

*Based on 19 SMSAs.

TABLE B-6. ESTIMATED BENEFITS OF THE REDUCTION IN THE ANNUAL AVERAGE ARITHMETIC MEAN OF SO_2 WITHIN AN SMSA TO 60 $\mu g/m^3$* (discounted present value in thousands of 1980 $)

SMSA	Range	
	Low	High
Buffalo	$ 75,100	$107,286
Cleveland	31,836	45,480
Pittsburgh	218,592	312,275
Total	$325,528	$465,041

*Based on 19 SMSAs.

TABLE B-7. ESTIMATED BENEFITS OF THE REDUCTION IN THE MAXIMUM OF THE SECOND HIGHEST SO_2 READINGS WITHIN AN SMSA TO 260 $\mu g/m^3$* (discounted present value in thousands of 1980 $)

SMSA	Range	
	Low	High
Buffalo	$ 233,879	$ 334,113
Chicago	708,672	1,012,389
Cincinnati	193,161	275,945
Cleveland	384,152	548,788
Milwaukee	343,803	491,148
Minneapolis	529,176	755,965
New York	2,041,944	2,917,063
Philadelphia	813,595	1,162,279
Pittsburgh	341,364	487,663
St. Louis	389,094	555,849
Total	$5,978,840	$8,541,202

*Based on 19 SMSAs.

TABLE B-8. ESTIMATED BENEFITS OF THE REDUCTION IN THE MAXIMUM OF THE ANNUAL ARITHMETIC MEANS OF SO_2 WITHIN AN SMSA TO 60 $\mu g/m^3$* (discounted present value in thousands of 1980 $)

SMSA	Range	
	Low	High
Buffalo	$ 187,274	$ 267,535
Cleveland	104,346	149,065
Milwaukee	181,682	259,546
Minneapolis	127,309	181,870
New York	1,883,070	2,690,101
Philadelphia	415,176	593,109
Pittsburgh	296,879	424,113
Total	$3,195,736	$4,565,339

*Based on 19 SMSAs.

SECTION 6

LABOR SERVICES MARKET

SECTION 6

LABOR SERVICES MARKET

SUMMARY

Section 5 of this report reviewed the studies that have analyzed site differentials in residential property values as a basis for estimating the willingness to pay for air quality. The results of that review were used to provide a cross-check on the benefits estimated by the household expenditure model (Section 4). The basic approach in most of the residential property value studies reviewed in Section 5 involved the use of the hedonic price technique. In this section, the hedonic technique is applied to the market for labor in order to develop an additional cross-check on the benefits estimated in the household sector. Like the benefits estimated through the analysis of residential property value differentials, it is expected that the benefits estimated from wage rate differentials will be higher than the benefits estimated by the household expenditure model. This is because wage rate differentials will tend to reflect some of the aesthetic and health effects of locational differences in air pollution, as well as the effects of soiling and materials damage that are estimated by the household expenditure model.

In this section, socioeconomic data from the Panel Study of Income Dynamics (1) and air quality data from Air Quality Data -- Annual Statistics (2) are used to estimate hedonic wage equations. The hedonic wage equation identifies the influence of job characteristics, worker characteristics and amenities on wage rates in a local area. Through the estimation of these equations, it has been found that a significant positive relationship exists between total suspended particulate (TSP) levels and wage rates. These results suggest that individuals are paid higher wages in compensation for working in an area that experiences relatively high levels of TSP. Consequently, this suggests that reductions in TSP concentrations could reduce the amount of additional compensation required. The results described above are used to estimate the benefits of meeting the current secondary standard for TSP in the Cleveland and Denver SMSAs. These benefits, along with the benefits estimated for these SMSAs by the household expenditure model, are reported in Table 6-1. For Cleveland, the reduction in the level of TSP in 1987 is estimated to result in a reduction in the annual wage of $189.40 in 1980 dollars. Similarly, the reduction in the level of TSP in Denver will result in a reduction in the annual wage of $212.40. As Table 6-1 shows, the estimates for both of these SMSAs exceed the per-household benefits in 1987 estimated from the household expenditure model.

TABLE 6-1. COMPARISON OF THE PER-HOUSEHOLD BENEFITS OF ATTAINING THE CURRENT SECONDARY STANDARD FOR TSP*

SMSA	Hedonic wage model	Household expenditure model
Cleveland	$189.40	$6.23
Denver	$212.40	$7.39

* Discounted present value in 1980 of the per-household benefits occurring in 1987, at a 10 percent discount rate, in 1980 dollars. Benefits based on alternative secondary standards for TSP of 150 $\mu g/m^3$, not to be exceeded more than once a year, and a 60 $\mu g/m^3$ annual mean.

METHODOLOGY

The hedonic technique was explained in detail in Section 5 of this report. The reader is therefore referred to that section for a complete explanation of the hedonic technique.* In this subsection, a brief summary of the hedonic technique as applied to the market for labor will be given.

The general form of a hedonic equation relates the price of a good to the characteristics of that good. The market for jobs, however, differs from the consumer goods markets, since employers are not indifferent to the identity of workers to whom they "sell" their jobs (8). Consequently, the hedonic wage equation relates the wage for a particular job to the characteristics of the job and to the characteristics of the worker. This relationship can be expressed as:

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* See Lucas (8) for an excellent explanation of the application of the hedonic technique to the labor market.

$$W_i^{\alpha} = W(E_i, P^{\alpha}) \tag{6.1}$$

where W_i^{α} = the equilibrium wage rate for worker α performing job i.

E_i = a vector of characteristics of job i.

P^{α} = a vector of characteristics of worker α.

The partial derivative of the wage rate with respect to the job and worker characteristics can be interpreted as the marginal implicit prices of these characteristics or the additional amount that must be paid for a job or worker with one more unit of a particular characteristic. Since one of the basic assumptions of the hedonic technique is that the market for the "good" is in equilibrium, the hedonic equation is a reduced form equation where the marginal implicit price of each characteristics is equal to the marginal willingness to pay a worker (in terms of the employer) or marginal willingness to accept a job (in terms of the employee) with one more unit of that characteristic. With respect to a job with an environmental characteristic such as the level of air pollution, the partial derivative of the hedonic wage equation with respect to air quality can provide an estimate of the implicit price of air quality and therefore the equilibrium marginal willingness to accept a job with one more "unit" of air pollution. The hedonic equation can consequently be used to estimate the benefits of marginal improvements in the level of air pollution.*

DATA

Equation (6.1) expresses the equilibrium wage rate (W_i^α) as a function of a vector of worker characteristics (P^α) and a vector of job characteristics (E_i). In this study, the vector P^α is assumed to contain measures of: (1) whether the individual is a union member (UNION), (2) whether the individual is a veteran (HVET), (3) the size of the individual's family (FMSZ), (4) the individual's health status (HLTH), (5) the individual's prior educational achievement (EDC2, EDC3), and (6) the length of time the individual has spent on his present job (TOJ2). Next, E_i contains measures of: (1) mean January and July temperature in the individual's area of residence (COLD, WARM), (2) the job accident rate in the industry where the individual works (JACR), (3) average rainfall in the individual's area of residence (HUMD), and (4) levels of the air pollutants sulfur dioxide (SO_2), total suspended particulates (TSP), and nitrogen dioxide (NO_2).

Unfortunately, this formulation may be subject to a specification error of unknown severity resulting from the omission of relevant explanatory variables. While the personal characteristics are fairly standard for analyses of this type, biased coefficient estimates may result from the exclusion of still other relevant job characteristic variables. That is, climate, job hazards, and air pollution may not exhaust the list of job characteristics that may affect the equilibrium wage rate. [For good surveys of the role other variables may play, see Brown (12) and Rosen (5).] Proximity to recreational opportunities and the amount of local social infrastructure are but two examples of work environment variables that could in principle be measured and included. Also, the more labor market specific variables used by Nakamura, Nakamura, and Cullen (7) have been excluded from consideration here. Because this analysis was done solely for the purpose of providing a cross-check on the basic household expenditure model, no efforts were made to collect observations on these potentially relevant variables.

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* Note that in this discussion, no distinction has been made between indoor air pollution in the work site as compared to atmospheric air pollution in the area of the work site. Clearly, both of these characteristics may be appropriate variables in the hedonic wage equation. In this analysis, however, only atmospheric pollution is considered. The implications of omitting a potentially relevant variable are discussed in a subsequent section.

The variables used to explain variations in the wage rate were chosen from those that had been collected previously by the Resource and Environmental Economics Laboratory at the University of Wyoming for use on other research projects. Specifically, the basic data set used to estimate the wage equation consisted of observations drawn from the Panel Study of Income Dynamics (PSID) (1) for the 1971 interview year. This data set gives the head of household's state and county of residence along with information on the characteristics of the head of the household. Consequently, data on environmental variables were collected by county and then matched to the individual observations obtained from the PSID. In total, there are observations for household heads on variables that can be used to construct a measure of their real wages, together with measures of the variables in the P_i^α and E_i vectors defined previously in Equation (6.1). The exact definitions of all of these variables as well as their sources are provided in Tables 6-2 through 6-5.

For the variables COLD, WARM and HUMD, the matching process was quite simple and requires no further elaboration. However, the matching of the air pollution variables to counties should be

TABLE 6-2. PECUNIARY VARIABLES

Variable	Definition
HOURS	Annual hours working for money by the head of household. Source: Reference (1).
AWGH	Annual money income from labor received by the head of household. Source: Reference (1).
WAGH	Per-hour money income from labor received by the head of household (i.e., WAGH = AWGH/HOURS). If HOURS = 0, then WAGH = 0. Source: Reference (1).
BDAL	Index of comparative living costs for a four-person family for various areas within the United States. The lowest living standard was used for the purpose of this study. Source: Reference (19).
RWGH	Real hourly money income from labor received by head of household (i.e., WAGH/BDAL). Source: Reference (19).

TABLE 6.3. PERSONAL CHARACTERISTIC VARIABLES

Variable	Definition
HLTH	If there are limitations on the type or kind of work that the head of the household can do, HLTH = 1; otherwise, HLTH = 0.
UNION	If head of household belongs to a labor union, UNION = 1; otherwise, UNION = 0.
EDC1	If head of household has completed grades 0-8 or has trouble reading, EDC1 = 1; otherwise, EDC1 = 0.
EDC2	If head of household has completed grades 9-12 plus possible non-academic training, then EDC2 = 1; otherwise, EDC2 = 0.
EDC3	If head of household has completed at least some college, then EDC3 = 1; otherwise EDC3 = 0.
HVET	If head of household is a veteran of the armed services, HVET = 1; otherwise, HVET = 0.
FMSZ	Number of people in each household.
TOJ1	If head of household has been employed at present job for 3 years or less, TOJ1 = 1; otherwise, TOJ1 = 0.
TOJ2	If head of household has been employed at present job for more than 3 years, TOJ2 = 1; otherwise, TOJ2 = 0.

Source: Panel Study of Income Dynamics. Reference (1).

TABLE 6-4. WORK ENVIRONMENT VARIABLES

Variable	Definition
WARM	Mean annual July temperature in °F x 10.0 in county of residence in 1970. Source: Reference (20).
COLD	Mean annual January temperature in °F x 10.0 in county of residence in 1970. Source: Reference (20).
HUMD	Mean annual precipitation in inches x 100.0. Source: Reference (20).
SO_2	Annual 24-hour geometric mean of sulfur dioxide as measured by the Gas Bubbler Pararosaniline-Sulfuric Acid Method (in $\mu g/m^3$) for a monitoring station within the county of residence in 1970. Source: Reference (1).
TSP	Annual 24-hour geometric mean of total suspended particulates as measured by the Hi-Vol Gravimetric Method for a monitoring station within the county of residence in 1970 (in $\mu g/m^3$). Source: Reference (1).
NO_2	Annual 24-hour geometric mean of nitrogen dioxide as measured by the Salzman Method for a monitoring station within the county of residence in 1975 (in $\mu g/m^3$). Source: Reference (1).
JACR	Number of disabling work injuries in 1970 for each million employee hours worked by 2- and 3-digit SIC codes. Source: Reference (21).

TABLE 6-5. AUXILIARY VARIABLES

Variable	Definition
AGE	Age of the head of household.
OCCUP	If head of household is blue collar worker, OCCUP = 0; otherwise, OCCUP = 1.
SEX	If head of household is a female, SEX = 0; otherwise, SEX = 1.
RACE	If head of household's race is white, RACE = 1; otherwise, RACE = 0.
REG1	If head of household lives in a Northeastern state, REG1 = 1; otherwise, REG1 = 0.
REG2	If head of household lives in a North Central state, REG2 = 1; otherwise, REG2 = 0.
REG3	If head of household lives in a Southern state, REG3 = 1; otherwise, REG3 = 0.
REG4	If head of household lives in a Western state, REG4 = 1; otherwise, REG4 = 0.
PRX1	If head of household's dwelling unit is within 5 miles of the center of a city with a population of 50,000 or more (hereafter referred to as city center), PRX1 = 1; otherwise, PRX1 = 0.
PRX2	If head of household's dwelling unit is within 5 to 14.9 miles of the city center, PRX2 = 1; otherwise, PRX2 = 0.
PRX3	If head of household's dwelling unit is within 15 to 29.9 miles of the city center, PRX3 = 1; otherwise, PRX3 = 0.
PRX4	If head of household's dwelling unit is within 30 to 49.9 miles of the city center, PRX4 = 1; otherwise PRX4 = 0.
PRX5	If head of household's dwelling unit is more than 50 miles from the city center, PRX5 = 1; otherwise, PRX5 = 0.

Source: Panel Study of Income Dynamics. Reference (1).

explained in greater detail.* The matching process was begun by listing each of the 669 counties in the 50 states where PSID families lived during 1970. Outdoor air pollution monitoring data existed for at least one of the three measures of SO_2, NO_2 and TSP for 247 of these counties. In cases where data from only one monitoring station in the county were available, those data were automatically assigned to all PSID families residing there. On the other hand, where data were available from multiple monitoring stations in the county, data from the single station that had operated for the greatest portion of the 9-year period 1967-1975 were selected. The monitoring stations selected using this rule tended to be at central city locations. Finally, since no pollution data were available for 422 counties (699 minus 247), values were assigned to the air quality variables for these counties by replacing the missing observations with either the means of the observed values for the pollutants or estimated using an amended version of a technique suggested by Dagenais (22). A brief discussion of the replacement with means method is outlined in Maddala (23). The amended variant of the Dagenais procedure would involve running a regression of each pollution variable on: (1) all remaining (non-pollution) explanatory variables in Equation (6.1), and (2) any relevant auxiliary variables that may be selected. The values of the missing observations are then predicted from these regressions. An alternative to either the replacement with means or the Dagenais procedures would be to restrict the sample to only those observations where actual measurements were available on all variables, including the pollutants. Even though this restriction reduced the available data set to 112 observations, it was employed in the estimation of one equation for illustrative purposes.*

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* The procedure used to assign air pollution measures to the individual observations is similar to that used by Crocker, Schulze, et al. (18).

It should also be mentioned that SO_2 data that are obtained using the Gas-Bubbler Pararosaniline-Sulfuric Acid Method have been shown to be biased downward. A correction factor was therefore developed in order to remove the bias from the SO_2 data measured by this method (see Section 3 for details regarding this correction).

For the purpose of estimating the hedonic wage equation, the data set was reduced from the roughly 3300 possible observations to 1395 observations after excluding all households where: (1) any family member received transfer income, (2) the head's annual hours of working for money were less than 400 hours. The first of these exclusions was made in order to reduce the statistical problem created by families that may be facing non-convex budget constraints, while the second was made in order to eliminate casual workers, who may be out of equilibrium because their asking wage may exceed the offered wage, from the sample. Curiously, after making these two exclusions, there were no families remaining in the sample where the head: (1)

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* Additionally, even if the NO_2 variable was eliminated from consideration, there would still have been only 432 families for whom data on both SO_2 and TSP could have been matched.

received income from overtime, bonuses or commissions, or (2) was self-employed.

The restricted sample used here is quite similar to that used by Wales (24) and Wales and Woodland (6,25) in their numerous papers on the empirical determinants of labor supply using PSID data. However, by excluding household heads who worked less than 400 hours, the estimates reported in the next section cannot be taken as representative of the general population. Instead, they apply only to those in the population having the same characteristics as those in the sample. In short, the estimates say little about the wage rate that would be paid to an individual working 400 hours or less had that individual chosen to work, for example, full time.*

SPECIFICATION

The exact specification of the wage equation used in the present study is:

$$\log(\text{RWGH}) = f\Big(\text{UNION, HVET, FMSZ, HLTH, EDC2, EDC3, TOJ2, WARM, JACR, COLD, HUMD, } SO_2\text{, TSP, } NO_2\text{, } (\text{TSP})^2\text{, } (SO_2)^2\text{, } (NO_2)^2\Big) \quad (6.2)$$

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* See Heckman (4,26) for a discussion of sample selectivity bias.

In Equation (6.2), the function f is linear in the parameters and RWGH denotes the real wage. Also, note that the squares of the levels of the three pollution variables are included as regressors in order to allow for possible nonlinearities in the way that air pollution affects the real wage. This equation was estimated by ordinary least squares for both the complete sample of 1395 observations and for selected partitions of this sample constructed on the basis of age (AGE), race (RACE), sex (SEX), and occupation (OCCUP). In particular, there were three age categories (17-29, 30-49, 50-69), two race categories (white, non-white), two sex categories (male, female), and two occupation categories (white collar, blue collar). The total number of possible partitioned regressions was therefore 24. However, not all of these possible regressions were actually estimated because for certain partitions the number of available observations was insufficient.*

EMPIRICAL RESULTS

As previously indicated, three basic versions of Equation (6.2) were estimated where: (1) the restricted sample of 112 observations was employed, (2) the replacement with mean procedure was used, and (3) the amended Dagenais procedure was used to construct values for the missing pollutants. All regressions were estimated by ordinary least squares (OLS).

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* Regressions for partitions containing less than 50 observations were not estimated. For these cases, the observations from two or more partitions were pooled and one regression was run on the combined data set.

Equation (1) of Table 6-6 reports the results from estimation with the restricted data set. In this equation, all of the personal characteristic variables are significant at the 1 percent level except HLTH and TOJ2. However, the work environment variables are all insignificant at conventional levels. In fact, the t-statistics on the pollution variables in no case exceed 1.1 in absolute value. Using the replacement with means procedure, the quality of the estimated coefficients improves considerably. These results are shown in Equation (2) of Table 6-6. With the increase in the number of observations (NOB) employed from 112 to 1395, all of the personal characteristic variables turn out to be significant at the 1 percent level and have the correct sign.

The estimates of the coefficients on the work environment variables also tend to be more highly significant and are more plausibly signed than in the case where the restricted sample of 112 observations is used. Also, they are generally consistent with the findings of other investigators. As indicated in Equation (2) of Table 6-6, the variables WARM and COLD enter with a significant negative sign. In the case of WARM, the negative sign indicates that the individuals in the sample are willing to accept a lower wage in order to live in an area with hot summers. That same qualitative result has been obtained by Rosen (16) where the number of sunny days

TABLE 6-6. HEDONIC WAGE EQUATIONS (standard error in parentheses)

Variable	Equation 1	Equation 2	Equation 3
CONSTANT	-30.473	1.505*	1.141*
	(37.253)	(0.465)	(0.322)
UNION	0.313*	0.127*	0.128*
	(0.107)	(0.028)	(0.028)
HVET	0.265*	0.187*	0.187*
	(0.089)	(0.026)	(0.026)
FMSZ	0.030**	0.022*	0.023*
	(0.015)	(0.005)	(5.54E-03)
HLTH	-0.202	-0.107*	-0.099*
	(0.153)	(0.037)	(0.037)
EDC2	0.205**	0.073**	0.075**
	(0.096)	(0.034)	(0.034)
EDC3	0.495*	0.491*	0.492*
	(0.111)	(0.039)	(0.039)
TOJ2	0.080	0.133*	0.128*
	(0.084)	(0.027)	(0.027)
WARM	0.942	-0.010*	-7.79E-03**
	(0.897)	(0.003)	(3.12E-03)
JACR	5.94E-05	0.001*	1.41E-03*
	(0.001)	(4.07E-04)	(4.07E-04)
COLD	-0.291	-0.008*	-7.39E-03*
	(0.214)	(0.003)	(1.80E-03)
HUMD	0.010	-0.002	-7.84E-05
	(0.007)	(0.001)	(1.38E-03)
SO_2	0.532	-0.003	1.85E-03
	(0.594)	(0.005)	(3.34E-03)

* Significant at the 1 percent level (two-tailed test).
** Significant at the 5 percent level (two-tailed test).

(continued)

TABLE 6-6 (continued)

Variable	Equation 1	Equation 2	Equation 3
$(SO_2)^2$	-3.05E-06 (5.67E-06)	-5.48E-06 (6.81E-05)	-9.71E-05 (6.12E-05)
TSP	-0.832 (0.785)	0.009** (0.005)	8.23E-03 (4.40E-03)
$(TSP)^2$	3.34E-06 (3.13E-06)	-5.09E-05** (2.31E-05)	-3.74E-05 (2.25E-05)
NO_2	0.039 (0.337)	0.002 (0.008)	1.65E-03 (1.94E-03)
$(NO_2)^2$	5.26E-07 (2.66E-06)	-2.52E-05 (8.57E-05)	-4.05E-06 (1.42E-05)
NOB	112	1,395	1,395
R^2	0.59	0.30	0.31
ε_{TSP}	--	-0.016	--

* Significant at the 1 percent level (two-tailed test).

** Significant at the 5 percent level (two-tailed test).

was used as a climate variable with individual data from the Current Population Survey together with SMSA-specific attributes. Hoch (15) and Cropper (17) also found that higher temperatures result in a lower wage. On the other hand, the negative sign on COLD suggests that individuals must be paid a premium to live in areas where mean January temperatures are low and winter weather is probably severe. Of the three studies just mentioned, only the one by Hoch employs a similar variable. The coefficient on "winter temperature" is positive in his regressions on Samples I and II and negative in his regression on Sample III [see Hoch (15), p. 39].

Next, the coefficient on JACR is positive and significant, supporting Viscusi's (11) result that employers must pay a premium in order to induce workers to accept jobs where the probability of accidents is higher. Also, this result is consistent with the findings of other investigators who measured other dimensions of working conditions. For example, Lucas (8), Hamermesh (9), and Thaler and Rosen (10) consider the effect of variables on wages, including: (1) a generalized measure of poor working conditions, (2) the presence of hazardous materials and/or equipment, and (3) deaths per 1,000 man-years of work. All three of these variables have been found to be positively and significantly related to dependent variables that are similar to the one used in the present study.

With respect to the HUMD variable, Equation (2) shows that its coefficient is negative but statistically insignificant at the 5 percent level. Although this negative sign is intuitively implausible, that same sign was obtained for the precipitation variable in Hoch's (15) regressions on each of his three samples. Rosen (16), however, obtains the more appealing result that increases in precipitation are positively associated with real wages. The precipitation variable that Rosen uses, which is defined as number of rainy days, was always positive and usually statistically significant in each of 29 different equation specifications [see Rosen (16) p. 94].

The pollution variables do not perform quite as well as the other variables in the equation. Both the linear and quadratic terms for SO_2 and NO_2 are statistically insignificant at the 5 percent level. The result for SO_2 conflicts with those of Cropper (17). In her regression for all earners and in four of her eight occupation-specific regressions, a measure of SO_2 turned out to be positively and significantly related to median earnings of males who were employed full time. However, in the Cropper study, SO_2 was the only pollution measure used and, therefore, this variable could also be proxying the effects of other pollutants. Rosen's (16) results show that this conjecture is a real possibility. His SO_2 measure occasionally has the right sign, but is more frequently negative. Particulates, on the other hand, exhibit superior performance in Rosen's equation. This variable was positive in each of the 32 cases where it was used and had a t-statistic exceeding 2 in 27 cases (again, see Rosen (16), p. 94). The results on the TSP variable used in the present study compares favorably with the findings of Rosen. As Equation (2) of Table 6-6 shows, the linear TSP term has a positive and statistically significant coefficient and the quadratic TSP term has a smaller negative but significant coefficient.

The elasticity of the real wage with respect to a change in TSP can be computed from the estimates presented in Equation (2) according to:

$$\varepsilon_{TSP} = \frac{\partial RWGH}{\partial TSP} \cdot \frac{TSP}{RWGH} = \alpha \cdot TSP + 2\beta \ TSP^2 \qquad (6.3)$$

where ε_{TSP} denotes the elasticity of the real wage with respect to TSP, α denotes the estimated coefficient on the linear TSP term, and β denotes the coefficient on the quadratic TSP term.* Evaluated at the mean of the values for TSP in Equation (2), the elasticity is equal to -0.016. In the neighborhood of the mean value of TSP, this elasticity indicates that an increase in the level of TSP will result in a decrease in the offered wage. Although this is contrary to our a priori expectations regarding the relationship between the wage rate and the level of air pollution, this negative elasticity results from the relatively high value for the mean of TSP. This high mean can be attributed to a number of counties in the data set where the annual averages of total suspended particulates were considerably in excess of 100 $\mu g/m^3$. For annual average TSP readings beneath 92.83, ε_{TSP} is positive and indicates that at TSP levels beneath 92.83, an increase in the level of TSP will have a positive effect on the wage rate. This is consistent with our hypothesis that workers must be paid a premium in order to work in areas with polluted air.

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* The elasticity is a measure of the percentage change in the dependent variable that can be expected from a percentage change in the independent variable.

The results from the estimation using the amended Dagenais procedure to construct the missing observations on the pollution variables are reported in Equation (3) of Table 6-6. The coefficients on the personal characteristic variables reported in Equation (3) are very similar to those reported in Equation (2). However, both the linear and quadratic terms for all three pollutants enter the pooled regression insignificantly at the 5 percent level using a two-tailed test.

Various partitions of the hedonic wage equation based upon age, race, and sex were also estimated. In total, 16 partitioned equations were estimated. In these regression equations, the air pollution variables are seldom significantly different from zero. More specifically, there are five of these regressions where one of the pollution variables entered significantly. The results of these regressions are reported in Equations (1) through (5) of Table 6-7. Respectively, the equations reported in this table are based on the partitioned data sets of:

TABLE 6-7. HEDONIC WAGE EQUATIONS ESTIMATED FOR PARTITIONED DATA SETS (standard error in parentheses)

Variable	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5
CONSTANT	-1.944 (1.220)	0.197 (1.460)	1.904* (0.793)	-0.406 (0.907)	3.795** (1.236)
UNION	0.076 (0.089)	0.143 (0.102)	0.165* (0.071)	0.347** (0.063)	0.149 (0.132)
HVET	-0.090 (0.080)	0.115 (0.082)	0.135* (0.064)	-0.060 (0.064)	—
FMSZ	-9.59E-03 (0.022)	-0.011 (0.023)	0.020 (0.019)	0.026* (0.011)	-9.42E-03 (5.39E-02)
HLTH	-0.069 (0.084)	-2.20E-03 (0.119)	-0.018 (0.097)	-0.200* (0.094)	-0.169 (0.166)
EDC2	0.273* (0.106)	-0.065 (0.097)	6.95E-03 (0.083)	-0.049 (0.063)	0.157 (0.204)
EDC3	0.518** (0.107)	0.066 (0.162)	0.026 (0.100)	-0.032 (0.112)	0.393 (0.213)
TOJ2	-0.032 (0.073)	0.283** (0.086)	0.359** (0.070)	6.21E-03 (0.065)	-0.013 (0.105)
WARM	-0.017 (8.71E-03)	7.386 (0.015)	-0.012 (7.38E-03)	-7.91E-03 (8.16E-03)	5.50E-03 (0.012)
JACR	-1.47E-03 (1.20E-03)	1.80E-03 (1.49E-03)	2.91E-04 (1.01E-03)	2.27E-03* (9.50E-04)	-1.07E-04 (1.92E-03)
COLD	3.85E-03 (6.86E-03)	5.02E-03 (8.58E-03)	-8.95E-03 (5.14E-03)	8.95E-03 (4.55E-03)	-0.012 (8.91E-03)
HUMD	5.09E-04 (4.47E-03)	4.37E-04 (5.62E-03)	-9.97E-04 (3.62E-03)	6.88E-03* (3.08E-03)	-7.08E-04 (5.40E-03)
SO_2	6.72E-03 (0.013)	-0.013 (0.012)	-0.024** (8.41E-03)	0.019 (0.010)	2.39E-03 (0.013)
$(SO_2)^2$	-5.03E-05 (2.48E-04)	1.71E-04 (2.27E-04)	4.68E-04** (1.69E-04)	-3.13E-04* (1.46E-04)	-2.72E-04 (2.49E-04)
TSP	0.010** (0.030)	0.026* (0.012)	8.56E-03 (0.010)	0.011 (9.76E-03)	-0.051** (0.018)
$(TSP)^2$	-5.21E-04** (1.68E-04)	-1.10E-04 (5.58E-05)	-2.90E-05 (5.26E-05)	-2.83E-05 (4.96E-05)	3.01E-04** (1.05E-04)
NO_2	-6.61E-03 (6.40E-03)	4.85E-03 (6.12E-03)	1.89E-03 (5.24E-03)	-1.99E-05 (4.30E-03)	-0.015 (8.49E-03)
$(NO_2)^2$	3.20E-05 (4.38E-05)	4.88E-05 (3.58E-05)	-2.41E-05 (3.47E-05)	7.44E-06 (3.69E-05)	7.18E-05 (5.57E-05)
NOB	126	74	178	127	67
R^2	0.38	0.43	0.35	0.53	0.39
ε_{SO2}	—	—	-0.313	0.296	—
ε_{TSP}	4.844	1.420	—	—	-2.158

* Significant at the 5 percent level (two-tailed test).

** Significant at the 1 percent level (two-tailed test).

(1) The Male, White, White Collar Worker, Age 50-69,

(2) The Male, White, Blue Collar Worker, Age 30-49,

(3) The Male, White, Blue Collar Worker, Age 17-69,

(4) The Male, Non-White, Blue Collar Worker, Age 30-49, and

(5) The Female, White, White Collar Worker, Age 17-69.

Neither the linear nor the quadratic term on NO_2 was significantly different from zero at the 5 percent level in these partitioned equations. In the five cases where a pollution variable was significant, the elasticity of the real wage with respect to a change in the pollution was computed using the method shown in Equation (6.3). All of these elasticities were evaluated at the mean (computed over all 1395 observations) of the pollution variables. Finally, the results of the elasticity calculations are presented beneath the coefficient estimates for the equations to which they pertain. As indicated in Table 6-7, three of the calculated elasticities are positive while two are negative.

The relatively weaker performance of the pollution variables in the equations estimated using the amended Dagenais procedure can perhaps be attributed to several factors. First, although this method produces consistent prediction of the missing observations, this asymptotic property may say little about the finite sample properties of such a procedure, particularly when a large fraction of the observations are missing. Second, the consistency of this method depends upon the use of a generalized least squares procedure to estimate the hedonic wage equation that requires the solution of a set of simultaneous, nonlinear equations. Because of computational difficulties, OLS was used instead. In this setting, it is not clear what statistical properties can be claimed for this approach. Two other reasons for weak performance, which are also common to the replacement with means procedure, can be offered: (1) observations that do exist on the air pollutants may be measured with so much error that they provide a great deal of misinformation, and (2) after adjusting for the other factors included in each regression, air pollution, even if measured perfectly, may not appear to be an important determinant of wages paid for these equations.

BENEFIT CALCULATIONS

Like the hedonic property value models reviewed in Section 5 of this report, the hedonic wage equation estimated in this section yields the equilibrium valuation of air quality. As such, it can be used to estimate the change in the real hourly wage resulting from a marginal improvement in air quality. Moving from alternative primary to secondary standards, however, will involve non-marginal changes. In order to estimate accurately the changes in the real hourly wage, and hence the benefits, resulting from these changes in air quality, the supply price function of workers for air quality must be known. Since this supply price function is not known, the benefits of these non-marginal reductions are approximated in this section based solely on the information yielded by the hedonic price technique.

The derivative of the hedonic wage function with respect to TSP corresponding to Equation (2) of Table 6-6 is shown in Figure 6-1. This derivative, RWGH'(TSP), traces out the equilibrium marginal implicit wage that different heads of households will accept in order to work in environments with varying levels of TSP. Each point on RWGH'(TSP) corresponds to one point on each head of household's supply price function for TSP. A hypothetical supply price function of head of household i is shown in Figure 6-1 as $S(TSP)_i$. The positive slope of the supply price function indicates that worker i must be paid higher wages in order to induce him to work in an environment with

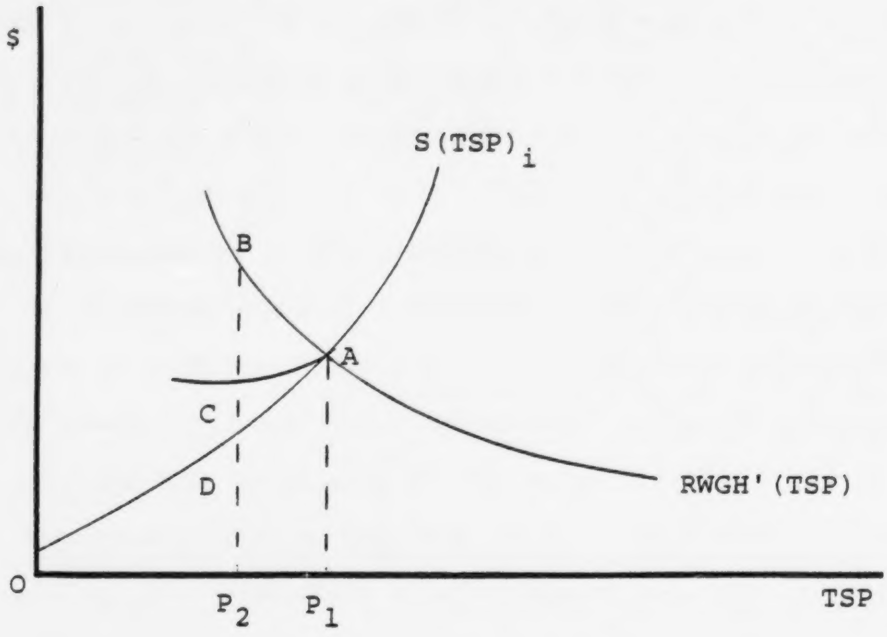

Figure 6-1. Alternative benefits estimates for a given change in air quality.

higher levels of TSP. As can be seen in Figure 6-1, RWGH'(TSP) is negatively sloped for values of the annual average of TSP within the range we are considering. Consequently, the equilibrium marginal implicit wage that workers are willing to accept decreases as TSP increases over this range. Intuitively, since pollution is a disamenity, one would expect that the equilibrium marginal implicit wage that workers would be willing to accept would be greater for higher levels of TSP. It is not clear, however, whether there are other factors not controlled for in the hedonic wage equation that may be correlated with TSP and hence may cause the plot of the equilibrium marginal wage to be negatively sloped.

The benefits of an improvement in TSP can be estimated by the area under the supply price function for air quality, $S(TSP)_i$. For the improvement in TSP from a primary standard, P_1, to a secondary standard, P_2, shown in Figure 6-1, benefits are estimated by the area P_1ACP_2. The supply price function for air quality has not been estimated in this analysis, however, and it is necessary to rely on information contained in the hedonic wage equation in order to approximate the benefits of the improvement in TSP from the primary to the secondary standard. The benefits of the improvement in TSP from P_1 to P_2 can be approximated by the area under the marginal implicit wage curve, RWGH'(TSP). Using this approximation technique, benefits are equal to the area P_1ABP_2. This technique implies that all the heads of household's marginal implicit wage functions are equal and increasing as TSP decreases. This may result in an overestimate of the true benefits of improvement.

Freeman (27) has suggested two alternative ways for approximating the benefits in the property value market of non-marginal changes in air quality from hedonic property value equations when the demand curve for air quality is not known. These approximation techniques can also be used to estimate the benefits to wage earners of an improvement in air quality when the supply price function for air quality is not known. For this study, we will use the approximation technique that is consistent with the *a priori* expectation that the supply price function of the head of the household for TSP decreases as TSP decreases. One point on the head of household's supply price function for TSP is known from the hedonic wage equation. This approximation technique assumes that the supply price function of the head of household declines linearly from that point to a zero marginal implicit wage for TSP when TSP has been completely abated. This linearly declining supply price function is shown as the line OA in Figure 6-1. For the reduction in TSP from P_1 to P_2, the benefits to the head of household can be approximated by the area P_1ADP_2. The benefits represented by this area can be easily calculated as the difference of triangle OAP_1 and ODP_2. This area is equal to:

$$\text{Benefits} = \frac{1}{2}\left[(AP_1 \cdot OP_1) - (DP_2 \cdot OP_2)\right] \qquad (6.4)$$

For the semi-log hedonic wage specification estimated in this section, this is equivalent to:

$$\text{Benefits} = \frac{(\alpha + 2\beta\ \text{TSP})\text{RWGH}}{2}\left[\text{TSP}_1 - \frac{\text{TSP}_2{}^2}{\text{TSP}_1}\right] \qquad (6.5)$$

where α = estimated coefficient of the linear TSP term.

β = coefficient of the quadratic TSP term.

TSP_1 = initial TSP level.

TSP_2 = TSP level after the implementation of the alternative secondary standard.

TSP = original TSP level predicted from the hedonic wage equation.

RWGH = the real wage predicted from the hedonic wage equation.

Depending on the shape of the actual supply price function for air quality, the approximation of benefits using this alternative may result in either an underestimate or overestimate of true benefits. Clearly, this alternative will result in a closer approximation of the true benefits of a given change in TSP than the benefits that would be estimated by the area under the derivative of the semi-log hedonic wage equation.

Illustrative calculations of the benefits of achieving secondary national ambient air quality standards (SNAAQS) are presented for two Standard Metropolitan Statistical Areas (SMSAs), Denver and Cleveland. These calculations are derived using the derivative of RWGH with respect to TSP of the pooled regression estimated in Equation (2) of Table 6-6 and the approximation technique just discussed.*

For TSP, it is assumed that neither community would have TSP levels higher than the primary standards for TSP by 1985 and that the secondary standards for TSP would be met by 1987. It is also assumed that air quality in these SMSAs will improve by half of the amount necessary to reach the secondary standard by the end of 1986 and improve by the remaining amount by the end of 1987. These improvements in air quality are assumed to be instantaneous, occurring on the last day of 1986 and 1987. Table 6-8 reports the alternative primary and secondary standards for TSP assumed to take effect in 1985 and 1987, respectively, and Table 6-9 reports 1978 annual average concentrations for the Denver and Cleveland SMSAs.

Annual benefit estimates from the abatement of TSP in the two cities are positive according to the calculations made here. For Denver, meeting the national secondary standard for TSP results in a reduction in the real wage from $4.1182/hour to $4.0120/hour. A similar calculation for Cleveland reveals that meeting this standard causes the real wage to fall from $3.8670/hour to $3.7723/hour.

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* Benefit calculations are not derived for the reductions in SO_2 and NO_2 to the secondary standard since the coefficients of these variables were not significantly different from zero in Equation (2) of Table 6-6.

TABLE 6-8. ALTERNATIVE AIR POLLUTION STANDARDS*
(annual average in $\mu g/m^3$)

	Primary standard	Secondary standard
SO_2	75	60
TSP	75	60
NO_2	100	100

* The source of the standards shown here is Stern _et_ _al_. (28).

TABLE 6-9. 1978 POLLUTION CONCENTRATIONS IN DENVER AND CLEVELAND SMSAs (annual average in $\mu g/m^3$)

	Denver	Cleveland
SO_2	16.9	61.49
TSP	86	72.2
NO_2	100	65.0

Projected benefits for these two SMSAs are obtained by multiplying the change in the hourly real wage by the annual hours of full time work and then multiplying this result by an estimate of the number of affected household heads in each SMSA. Annual hours of full time work were assumed to be 2000, and it was estimated that there would be approximately 458,000 household heads in Cleveland and 392,439 household heads in Denver in 1987 with the hours of work and employment characteristics required for inclusion in the sample used to make the pooled regression estimates. Since the secondary standard will be maintained in the future, it is necessary to project the future number of heads of household that will benefit from the attainment of the secondary standard for TSP. For the purposes of this study, it is assumed that the number of households in Denver and Cleveland will grow at an annual rate of 2.6 percent and 1.1 percent, respectively.* Using a 10 percent discount rate, benefits of $1.34 billion in 1980 dollars are estimated for the Denver SMSA. Benefits of $1.17 billion in 1980 dollars are estimated for the persons affected in Cleveland.

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* Annual growth rate estimated from information contained in Reference (29).

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